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DAVID E. FILSINGER

Mechanical Engineer

Defense Switching Network 787-4519

Commercial (513) 257-4519

EVALUATION OF CUSHIONING MATERIALS FOR MUNITIONS PACKAGING

HQ AFMC/LGTP
AIR FORCE PACKAGING EVALUATION ACTIVITY
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PROJECT NO. 87-P-117
TITLE: Evaluation of Cushioning Materials for Munitions Packaging

ABSTRACT

At the request of the Army Material Command (SMCAR) the Air Force Packaging Evaluation Activity has performed extensive dynamic cushioning tests on four grades of polyethylene cushioning material. The purpose of this testing was to generate new cushioning design curves that would define the cushioning properties of polyethylene over a greater range of drop heights and material thicknesses than those curves presently available.

It should be noted that all testing was performed on old materials blown with a chlorofluorocarbon (CFC) blowing agent. Therefore, the curves generated may not be representative of current materials produced using CFC free blowing agents.

PREPARED BY:

David Filsinger
Mechanical Engineer
AFPEA

PUBLICATION DATE:

REVIEWED BY:

Larry Wood
Ch, Materials Branch
AFPEA

APPROVED BY:

Leslie K. Clarke, III
Chief, AF Packaging
Evaluation Activity

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APPENDICIES

1.0 INTRODUCTION - At the request of the Army Material Command (SMCAR) the Air Force Packaging Evaluation Activity (AFPEA) agreed to perform dynamic cushion testing on several cushioning materials. The goal of this project was to generate cushioning design curves that would extend the limits of existing manufacturers curves. The existing curves usually include data generated from a one foot drop height to a four foot drop height at six inch intervals. At each drop height material thicknesses are chosen in one inch intervals from one inch to six inches in thickness.

1.1 AFPEA originally agreed to generate cushioning data on four standard densities of polyethylene material, a six pound crosslinked polyethylene and three bound fiber materials. The nature of the bound fiber materials was to be worked out at the conclusion of the polyethylene testing. Shortly after testing was initiated AFPEA was informed by the material supplier that two pound polyethylene produced with a chlorofluorocarbon (CFC) blowing agent was scheduled to be replaced with a new polyethylene produced with a CFC free blowing agent within the next year. In addition, the higher density polyethylene materials would be CFC free within a year or two and no guarantee could be made that the new material performance would be identical with the old material. When notified of the problems with the material changes SMCAR indicated a desire to continue with the testing anyway. AFPEA agreed that some useful information could be obtained by continuing the testing but would have to reduce the priority level of the project considering the questionable usefulness of the resulting data for design purposes.

2.0 DEFINITIONS

2.1 Drophead - The movable vertically guided weight used to impact the test cushions.

2.2 Equivalent free fall drop height - The calculated height of free fall in vacuum required for the drophead to attain a measured or given impact velocity.

2.3 G - The acceleration of an object divided by the acceleration of gravity.

2.4 Permanent set - The change in thickness of a material after being exposed to one or more compression cycles.

2.5 Peak G - The maximum G level recorded during deceleration of the drophead.

2.6 Static stress - Weight of the drophead divided by the area of the cushion.

2.7 Test sequence - The sequence of impacts required at one cushion thickness and drop height to collect data over the entire static stress range of interest.

3.0 AMBIENT TEST CONDITIONS

Temperature - 73^{o} F $\pm 5^{o}$ F

Relative humidity - 50% ±5%

4.0 TEST EQUIPMENT

4.1 Hardigg Cushion Tester

4.2 Impac Tester - Monterey Research Laboratories

4.3 Velocity meter - GHI Systems model EC700

4.4 Accelerometer - Endevco model 2233E piezoelectric transducer

4.5 Charge amplifier - Endevco model 2740B with 290 Hz two pole filter installed.

4.6 Data acquisition board - Data Translations model DT2801A

4.7 Computer - Tandon 286, PC-compatable

5.0 MATERIALS TESTED - Two, four, six, and nine pound density polyethylene using chlorofluorocarbon as the blowing agent were tested. The material was supplied by Dow Chemical Company and was cut to size by Foam Design, Inc. at their plant in Lexington, Kentucky.

6.0 DESCRIPTION OF TEST SAMPLES - All test samples were eight inches square. Sample thicknesses were one-half, one, two, four, and six inches. All samples greater than two inches thick were built up to thickness by bonding two or three layers of material together. Since bonding is a common industry practice we elected to use this procedure to permit the use of two inch material for all test sample thicknesses. It is not known to what extent this bonding may affect the data generated.

7.0 TEST PROCEDURE - All dynamic cushion testing was performed in accordance with MIL-HDBK-304B.

7.1 PREWORKING - Initial testing on the two and four pound materials was performed on preworked material. Five samples were preworked for each test sequence at drop heights of one, two, and three feet.

Preworking was performed sixteen to twenty-four hours before testing by using a compression tester to compress each sample ten times to fifty percent of its original thickness at a rate of ten inches per minute. Later in the testing program three additional samples for each of these test sequences were tested without preworking. The six and nine pound materials were not preworked because the loads generated by the procedure would have exceeded the capabilities of the compression tester.

7.2 STATIC STRESS POINT SELECTION - For ease of testing, fixed static stress points were chosen approximately equally spaced on a logarithmic scale. The points selected were .040, .064, .10, .16, .25, .40, .65, 1.0, 1.6, 2.5, 4.0, 6.5, and 10.0 psi. Impact data for the .040 and .064 points were obtained using an in-house constructed cushion tester (figure 1). Data collection for points .10 through 1.6 were performed using a Hardigg tester (figure 1) modified to obtain seven foot drop heights. Points 4.0 through 10.0 were done on an Impac tester (figure 2). The 2.5 psi static stress point could not be obtained as it was too high for the Hardigg and too low for the Impac tester.

7.3 SETTING DROP HEIGHT - First the cushion tester drophead weight was adjusted to obtain the desired static stress. Then using a setup cushion of the same material and dimensions as the cushions to be tested the drophead was raised to the approximate drop height required. The drophead was released and the impact velocity noted. By adjusting the release height up or down as required the procedure was repeated on the setup cushion until the desired impact velocity was obtained within one inch per second for three successive impacts. At static stress points of .10 and lower repeatability to within one inch per second was not always possible due to friction in the system and three inches per second variation had to be accepted.

7.4 STATIC STRESS RANGE SELECTION - The desired minimum static stress point for a test sequence was selected by successively lowering the static stress level until the peak recorded on the setup cushion exceeded 100 G's. The maximum static stress point was that point at which the peak again exceeded 100 G's.

7.5 DATA ACQUISITION - Data acquisition was performed using the following procedure.

a) The minimum static stress point and equivalent drop height velocity for the test sequence were selected and the drophead weight adjusted.

b) Using a setup cushion the drop head release point was adjusted to obtain the desired impact velocity. If the peak for the first

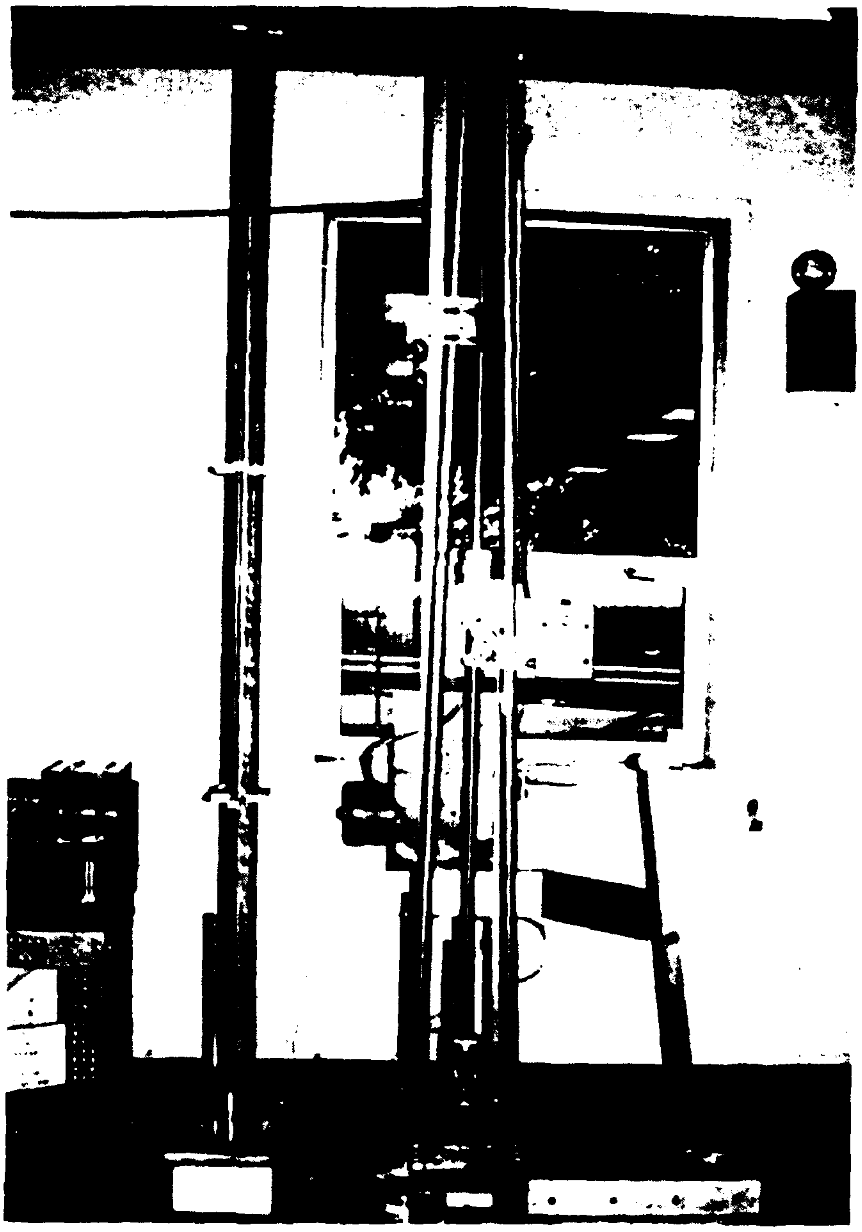


Figure 1. Low static stress dynamic cushion tester (left) and medium static stress Hardigg tester (center).

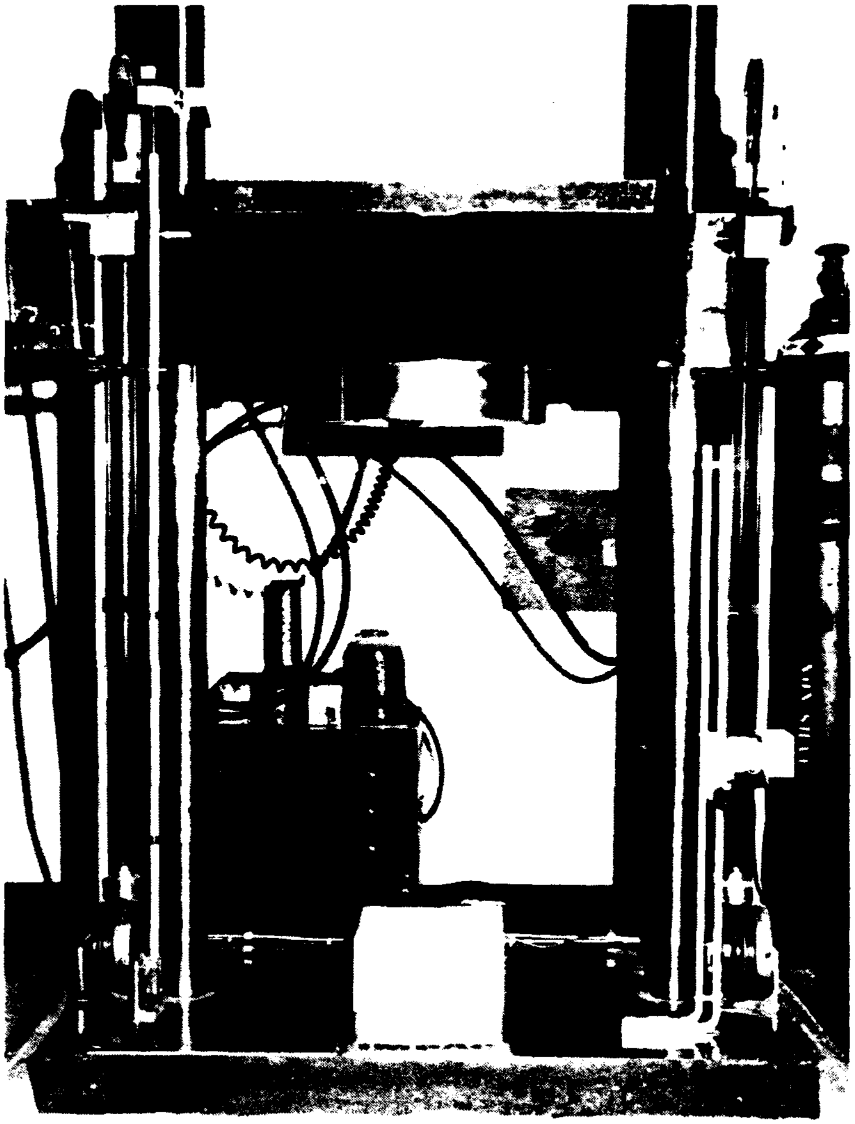


Figure 2. Monterey Research Laboratory, Inc. Impac tester for high static stress dynamic cushion testing.

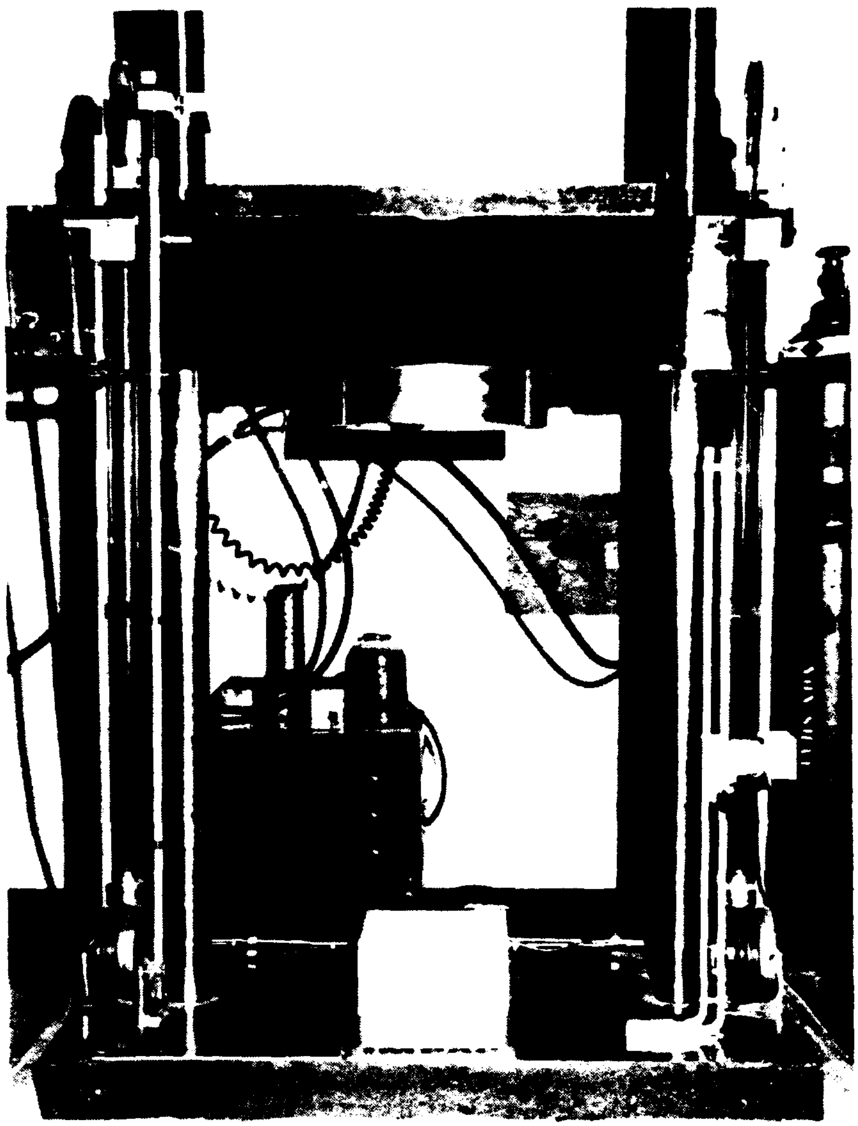


Figure 2. Monterey Research Laboratory, Inc. Impac tester for high static stress dynamic cushion testing.

has no problem with validating materials against specification curves when both the validation curves and specification curves are obtained with preworked materials it is another matter to say that these same curves are valid for design purposes. The final decision was in favor of not preworking the material. Therefore, it became necessary to repeat all of the previous tests to obtain new data on the one, two, and three foot drop test data. To obtain data more quickly and conserve test materials only three test samples were used for each sequence.

For the remainder of the testing with four and seven foot drops on two and four pound materials and all of the drops on six and nine pound materials the sample size was increased to eight test samples.

9.2 Physical sample dimensions - Eight inch square samples were chosen for all testing as this size is the standard size recommended in MIL-HDBK-304B for dynamic cushoning and is believed to be the size used by many industrial firms for their cushion testing. The sample thicknesses were selected by SMCAR.

9.3 Cushion dimension tolerances - Length and width dimensions were held to within $\pm 1/8$ inches giving a potential error of 3.1 percent in the calculation of static stress. The cushion thickness was held to within $\pm 1/16$ inches. This potential error of 12.5 percent for 1/2 inch cushions and 6.5 percent for one inch cushions may be significant. At two inch and greater thicknesses the thickness error is less than four percent. This error is considered acceptable. The effect of this error on peak G values can be estimated only by examination of the peak G/static stress curves when plotted by thickness for a given material and drop height. Such plots are displayed in the appendix.

9.4 Layered samples - The four and six inch samples were built up in layers from one and two inch materials glued together. The effect of this layering is unknown. It was noted during testing that all specimens bulged out on the sides after being significantly compressed at high static loadings. Those specimens that were layered bulged between the glue lines significantly more than at the glue lines. The glue apparently was acting as a restraining layer preventing horizontal expansion of the material.

9.5 Preworking - The use of preworking prior to dynamic compression testing of cushion materials is standard military testing practice when testing materials for conformance to standards. This preworking tends to produce more repeatable G levels during testing. The conformance curves in specifications such as PPP-C-1752 and MIL-P-26514 have been generated using preworked material. In hind sight, use of this procedure on the two and four pound materials may have been questionable as the practice may change the stiffness or other physical properties of the material.

9.6 Use of same cushion samples for entire test sequence - The procedures for performing dynamic cushion testing are outlined in each of two test documents; ASTM-D1596 and MIL-HDBK-304B. The two procedures are essentially identical with one exception. The ASTM procedure requires the use of a new set of cushion samples for each new test condition implying that new cushion samples should be used at each static stress point. Most commercial activities follow this procedure. MIL-HDBK-304B, used by government activities, recommends use of the same set of cushion samples for all static stress points unless the cushions sustain more than a 10 percent permanent set. Both approaches to generating dynamic cushioning curves have their advocates. ASTM-D1596 generated curves are useful for single item single shipment package design. Advocates of MIL-HDBK-304B feel that the testing procedure in the handbook produces a more conservative set of design curves better suited to military package design where multiple shipment, multiple use, long life containers are frequently used. AFPEA chose to use the MIL-HDBK-304B approach with the additional stipulation that the cushion samples would not be changed for any reason. Using the government technique for dynamic cushion testing offers a unique opportunity to compare the curves generated by both methods. Undoubtedly the retention of samples for an entire test sequence accounts for some of the differences seen between the data in this report and the manufacturer's data. It is our belief that the manufacturer's data should be used if the intent is to design a cushioning system to protect a one time shipment. However, if the cushions are to be reused many times or the item is to remain in the transportation/storage system for long periods of time and moved from time to time to new storage locations, as frequently happens in the military shipping and storage environment, then curves as generated in this report should be used.

9.7 Choice of static stress points - A standard practice at AFPEA is to choose static stress points that are equally spaced on a logarithmic scale and to plot these points on the same type of scale. Use of the logarithmic scale is useful for two reasons. First, the technique permits better definition of the low static stress end of the curve where G levels are rising very rapidly with small reductions in static stress. Second, polynomial curves can be fitted very successfully to the data points when the points are plotted on a logarithmic scale.

9.8 Filtering - Another standard practice at AFPEA is to filter the generated acceleration/time data electronically before capturing and analyzing the data. In technical terminology the filter used is a two pole Butterworth filter with a 3db cutoff frequency of 290 Hz. This filter is used to remove unwanted high frequency noise present on the signal. The appropriateness of our choice of filter is subjective, but was applied for this project.

9.9 Seismic mass considerations - For accurate measurement of acceleration pulses on a dynamic compression tester the base of the tester must remain firmly in place. In other words the base of the machine must not move downward under the force of the drophead impact. Any such movement reduces the magnitude of the acceleration measurement. Bolting the base of the machine to a concrete floor is not considered adequate. Standard practice is to use a mass at least 50 times the maximum drophead weight under the machine base and use grout between the base and the mass. This mass is known as a seismic mass. The grout prevents movement between the base and the mass by providing intimate contact between mass and base. AFPEA's Hardigg cushion tester is bolted and grouted to an eight thousand pound steel reinforced concrete mass some 80 times the mass of the 100 pound limit of the drophead. The Monterey Research Impac machine used for static stress points between 4 and 10 psi was not designed for this type of service. To obtain a 10 psi static stress on eight inch square cushions requires a 640 pound drophead backed up by a 32,000 pound seismic mass. It is estimated that the combined mass of the machine base, concrete pad, and concrete floor beneath amounted to one tenth of this figure. It is probable, therefore, that the peak accelerations measured on this machine are lower in magnitude than if a seismic mass had been used. In actual practice it would be rare for an item of 640 pounds to be dropped only on an unyielding surface. Therefore, we see these errors as justified and reasonable.

10.0 CONCLUSIONS

10.1 The timing of this project was not ideal. Because of the CFC removal process the data was being invalidated almost before it was collected. Dow Chemical and most of the other polyethylene suppliers were already experimenting with new blowing agents in order to supply CFC free cushioning materials. These new CFC free materials now are available for most densities. However, this situation does not imply that the time and money invested in this project were expended in vain. Much of the information learned in conducting this project, if used wisely on future testing, will produce higher quality more repeatable cushion design data than has been obtained on this or other previous efforts. With this goal in mind AFPEA has attempted to go into more detailed discussion of its findings in this report than would otherwise be necessary.

11.0 RECOMMENDATIONS - The following recommendations are being made in the hope that they will permit the acquisition of more reliable data.

11.1 Dimensional tolerances on test samples should be held to at least 3 percent and tighter if possible. Such tolerances will

preclude the testing of samples less than one inch thick unless extreme care is taken in cutting the samples.

11.2 Layered samples should not be used unless the manufacturer of the material normally supplies the material in this form.

11.3 When collecting cushion design data for polyethylene the test samples should not be preworked prior to testing. Preworking slightly softens the material and will adversely affect the data at the low end of the static stress curve. The effect probably is negligible at the high end of the curve as successive impacts act to prework the material anyway.

11.4 The choice of selecting new samples after each static stress point or of using the same samples for the entire test sequence should be made based on the intended use of the data. For military applications the latter alternative should be chosen.

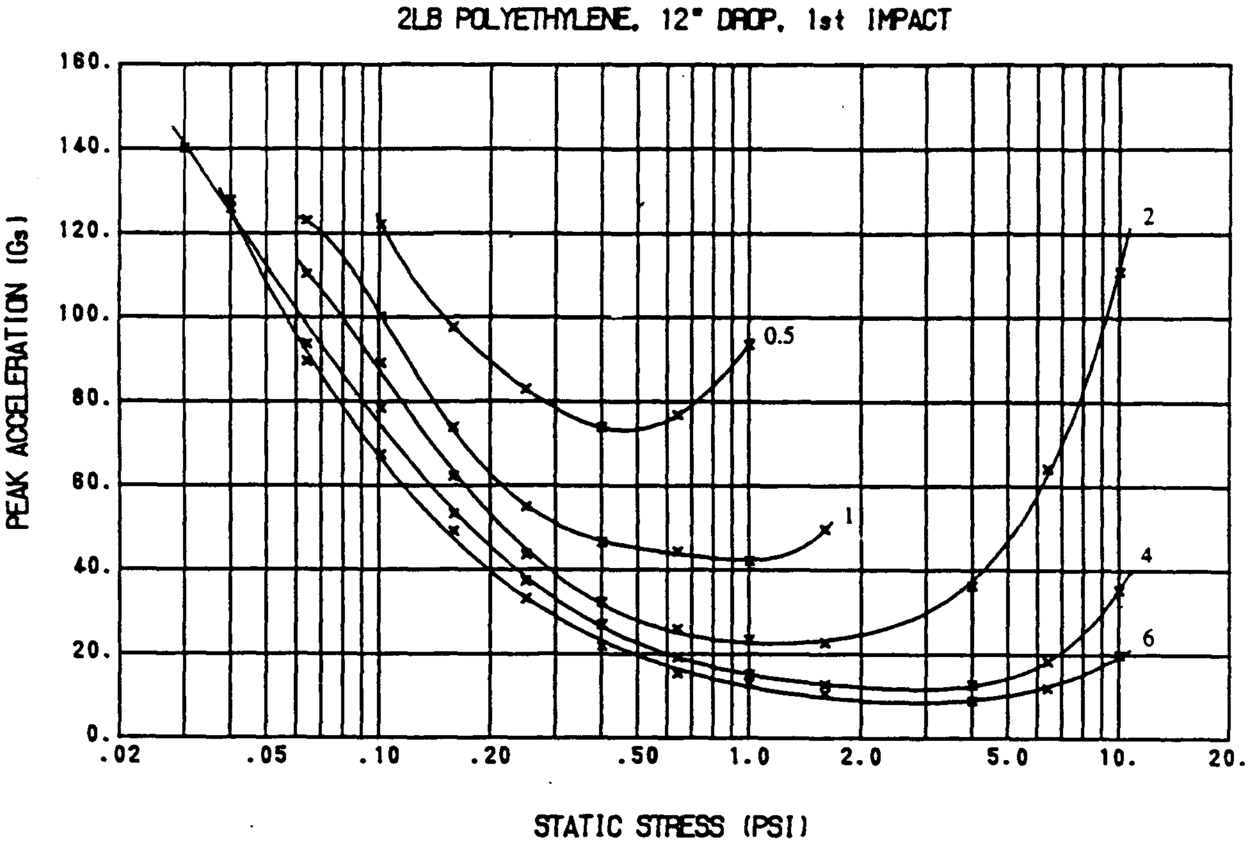
11.5 To more accurately define the low end of the static stress curve choose static stress points spaced evenly on a logarithmic scale and plot them on this same scale.

11.6 The subject of signal filtering to remove high frequency noise is a highly controversial subject and requires further study by both industry and government so that a standard filter can be agreed upon for general use in all cushion testing. With the use of a standard filter, data from diverse sources can be compared with greater confidence than is possible at present. As a starting point AFPEA would suggest a four pole filter with a 3 db cutoff frequency of 500 Hz. We do not recommend the use of digital filtering unless the filter algorithm permits setting a fixed cutoff frequency and attenuation rate.

11.7 AFPEA does not recommend the use of any dynamic cushion tester beyond the limits of the seismic mass beneath it. That is, the mass must be at least 50 times the weight of the dropping head. This recommendation imposes severe limits on testing at high static stress levels for most dynamic test machines when using eight inch square samples. If the sample dimensions are reduced to accommodate higher static stresses this reduction should be clearly noted as the reduction changes the ratio between the thickness and the other two dimensions. In no case should the thickness be greater than either the length or width of the specimen.

APPENDIX 1

IMPACT DATA PLOTS


2LB POLYETHYLENE, 12" DROP, 1st IMPACT
PEAK ACCELERATION (Gs)
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STATIC STRESS (PSI)
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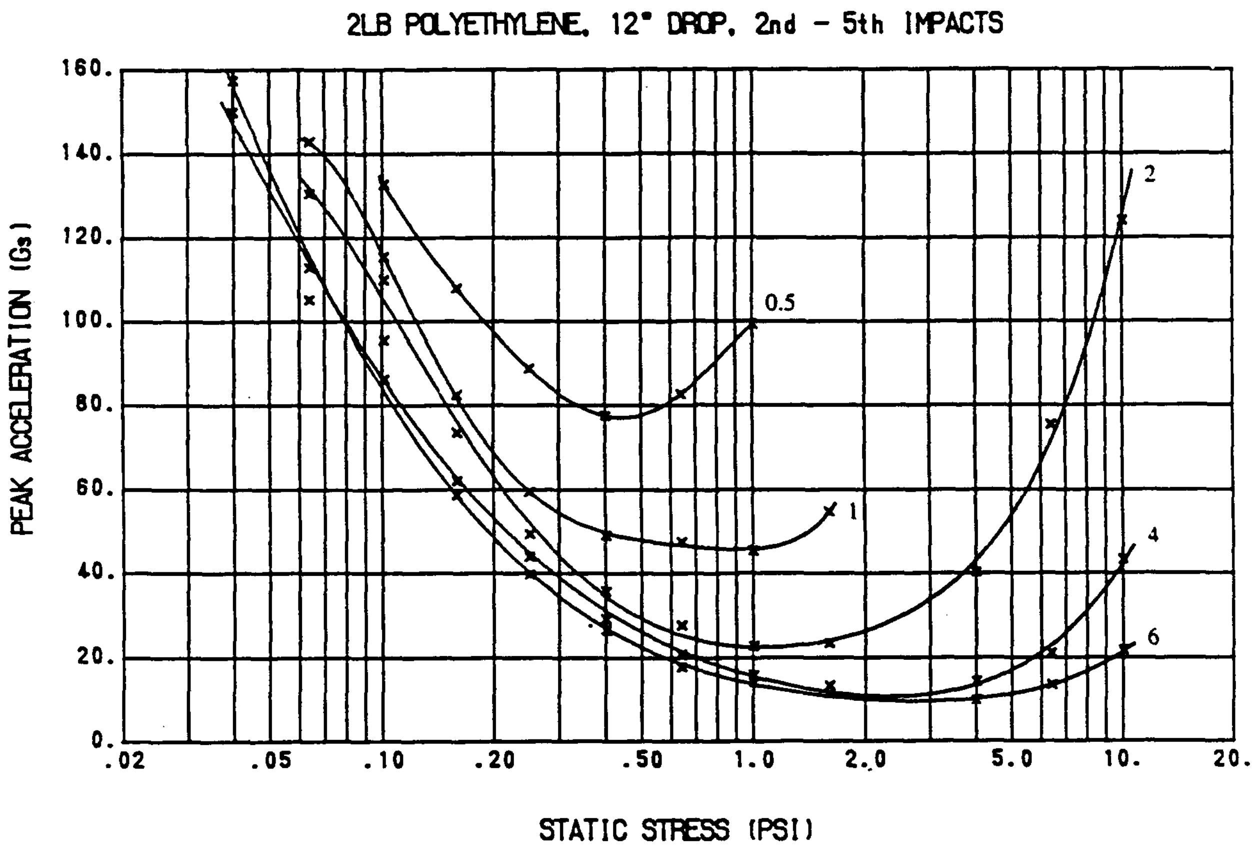
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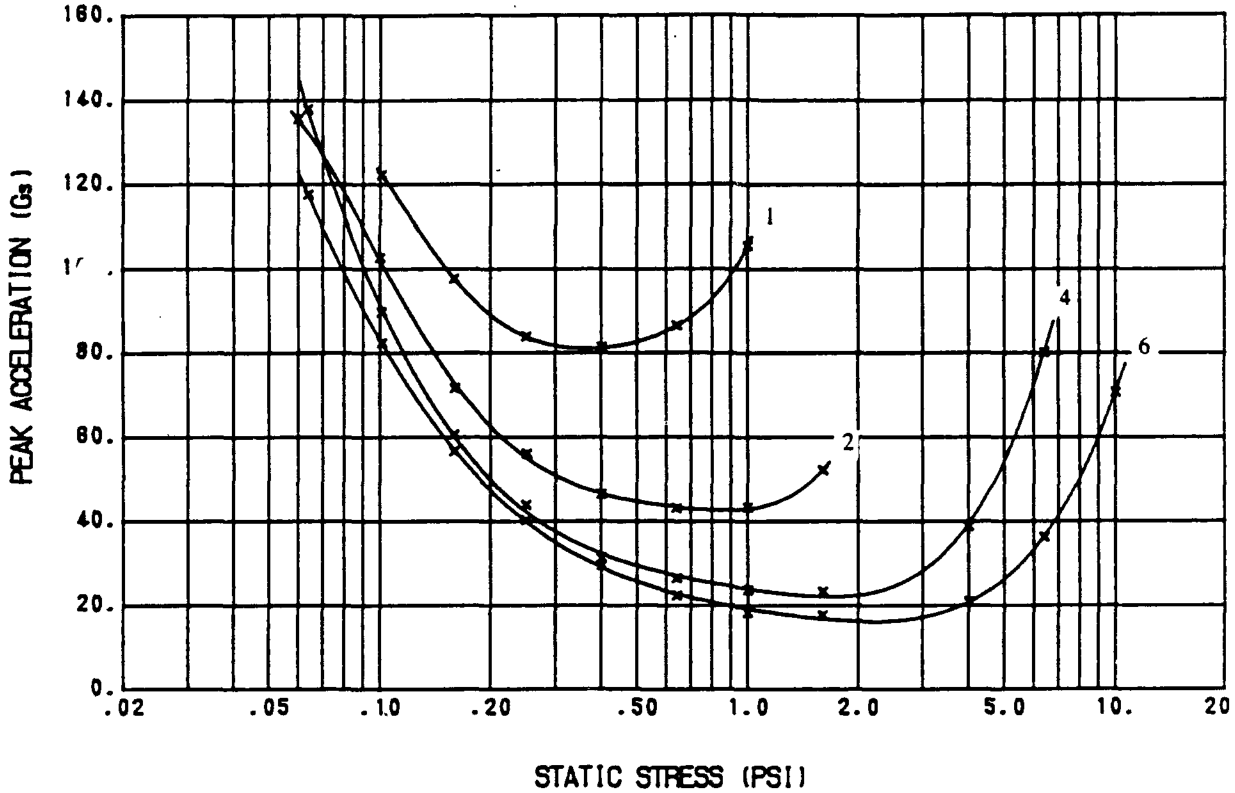
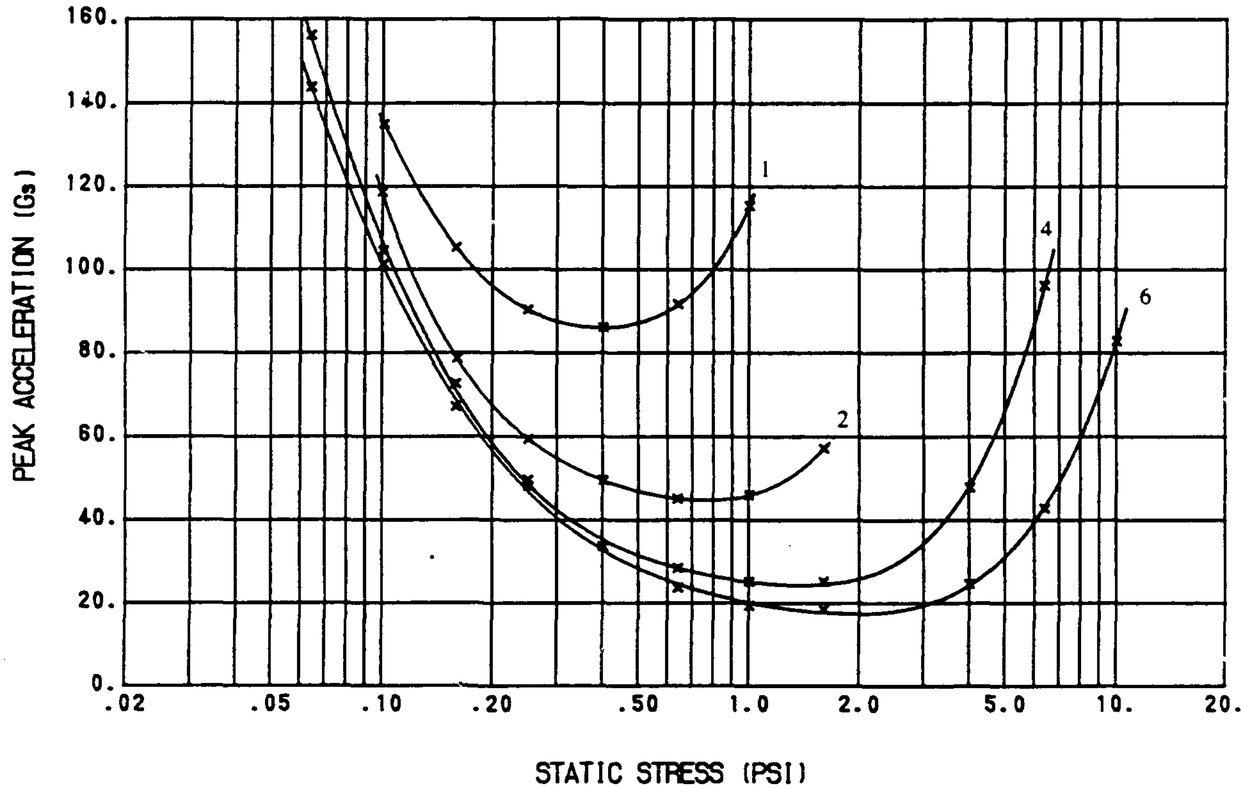
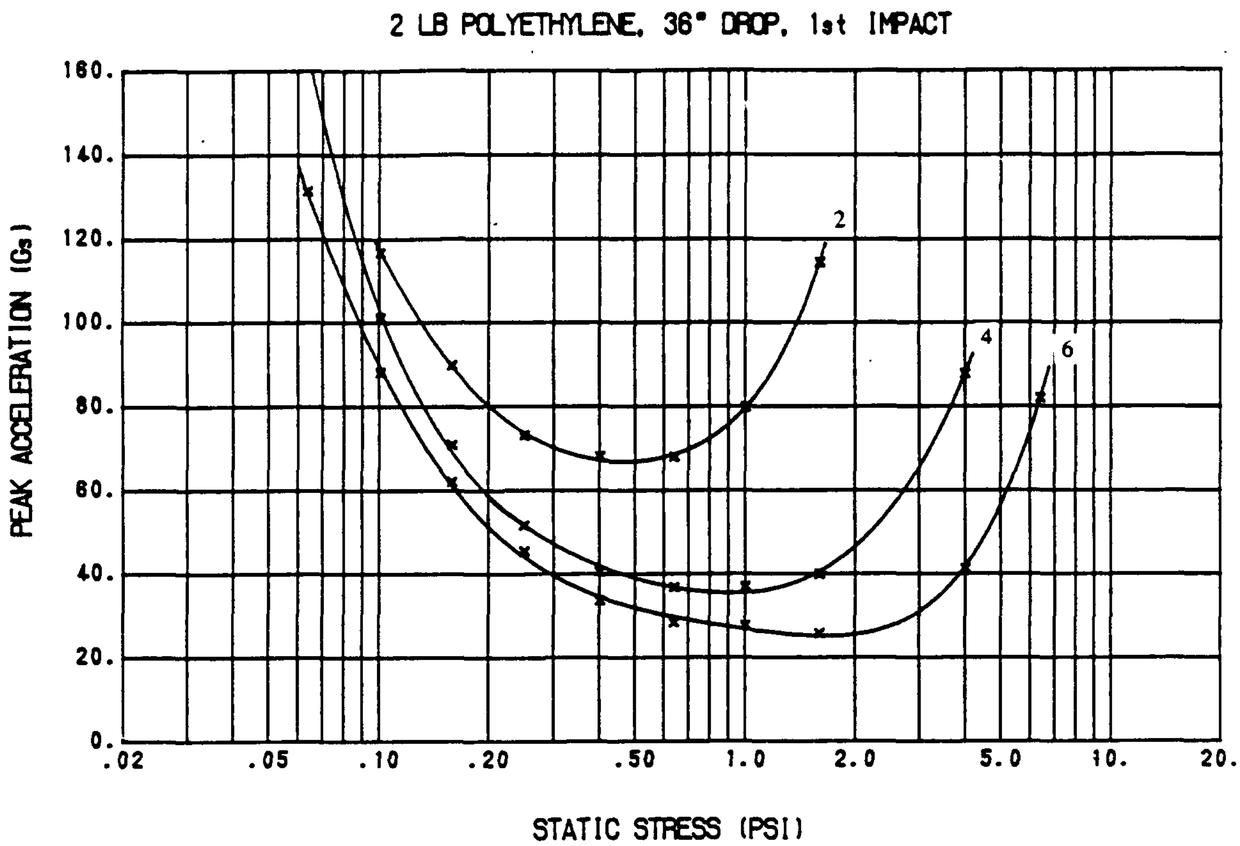
2 LB POLYETHYLENE, 24" DROP, 1st IMPACT



2LB POLYETHYLENE, 24" DROP, 2nd - 5th IMPACTS

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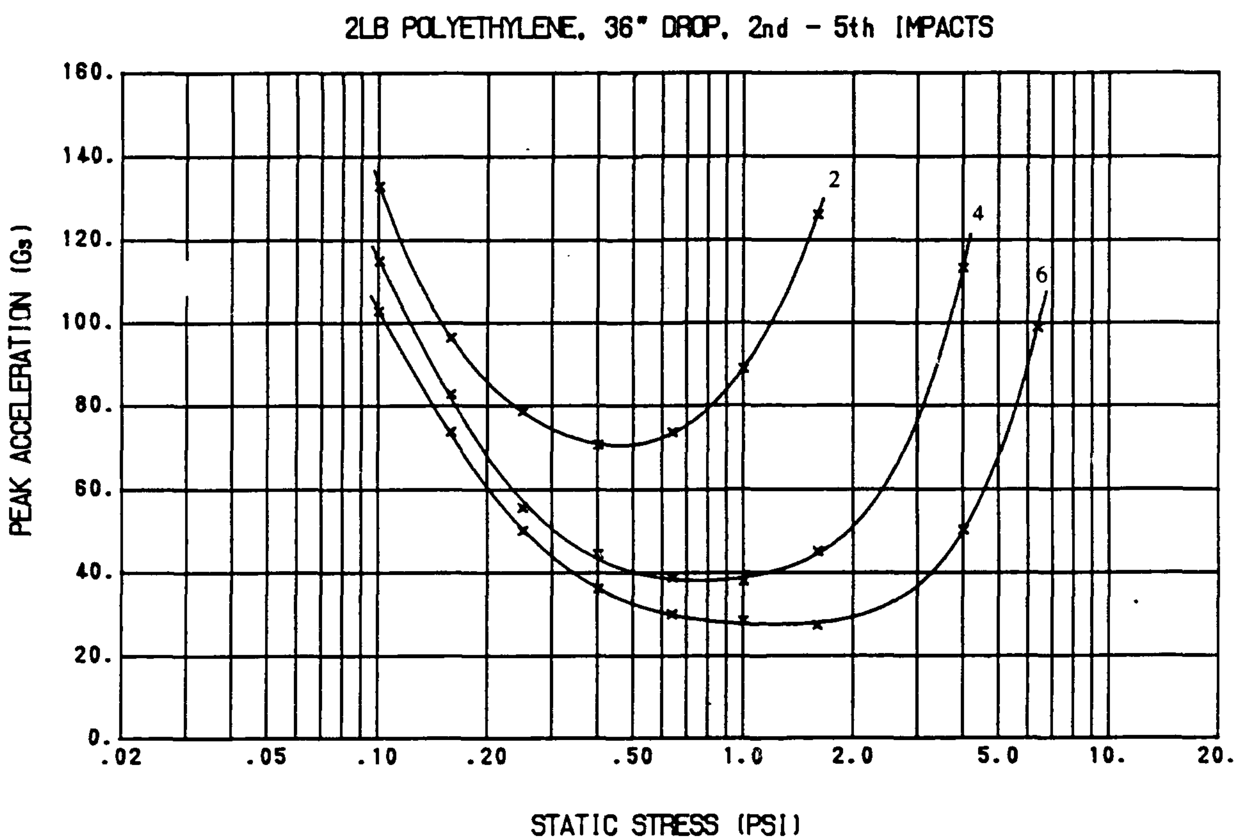
STATIC STRESS (PSI)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STATIC STRESS (PSI)

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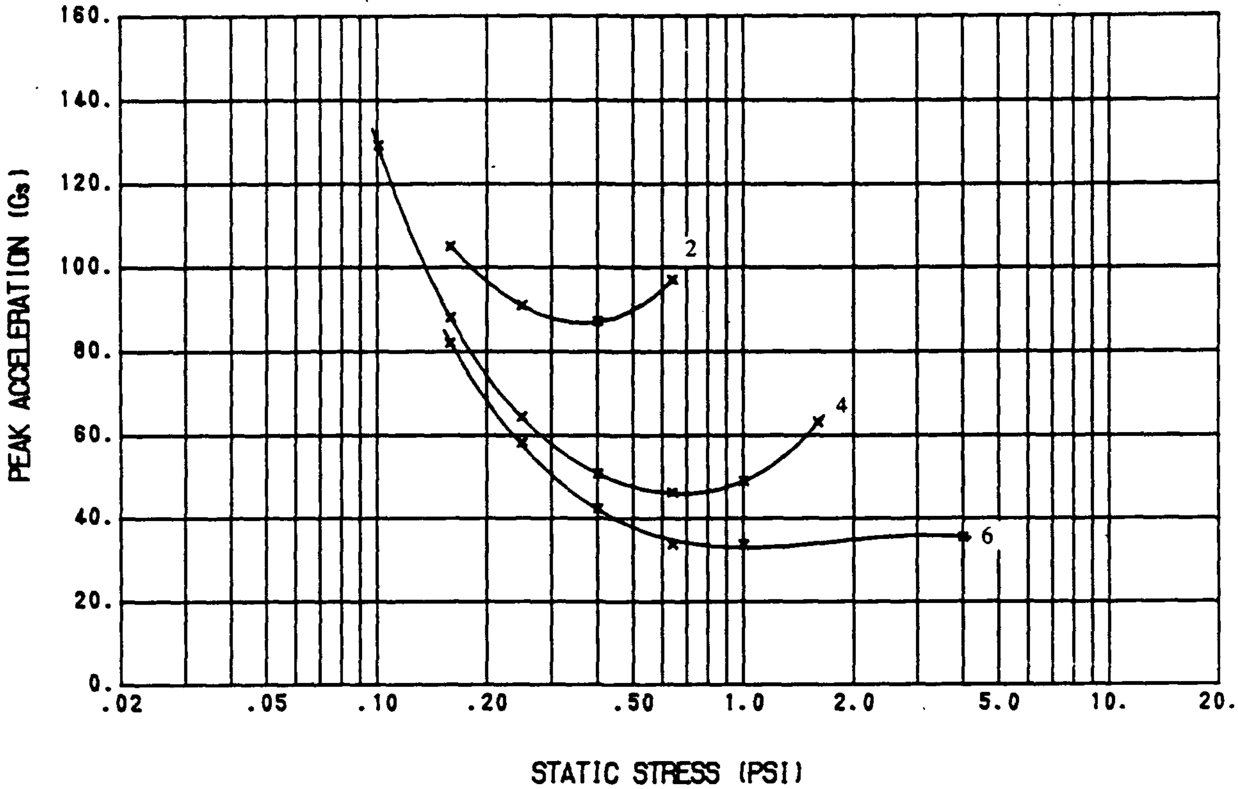

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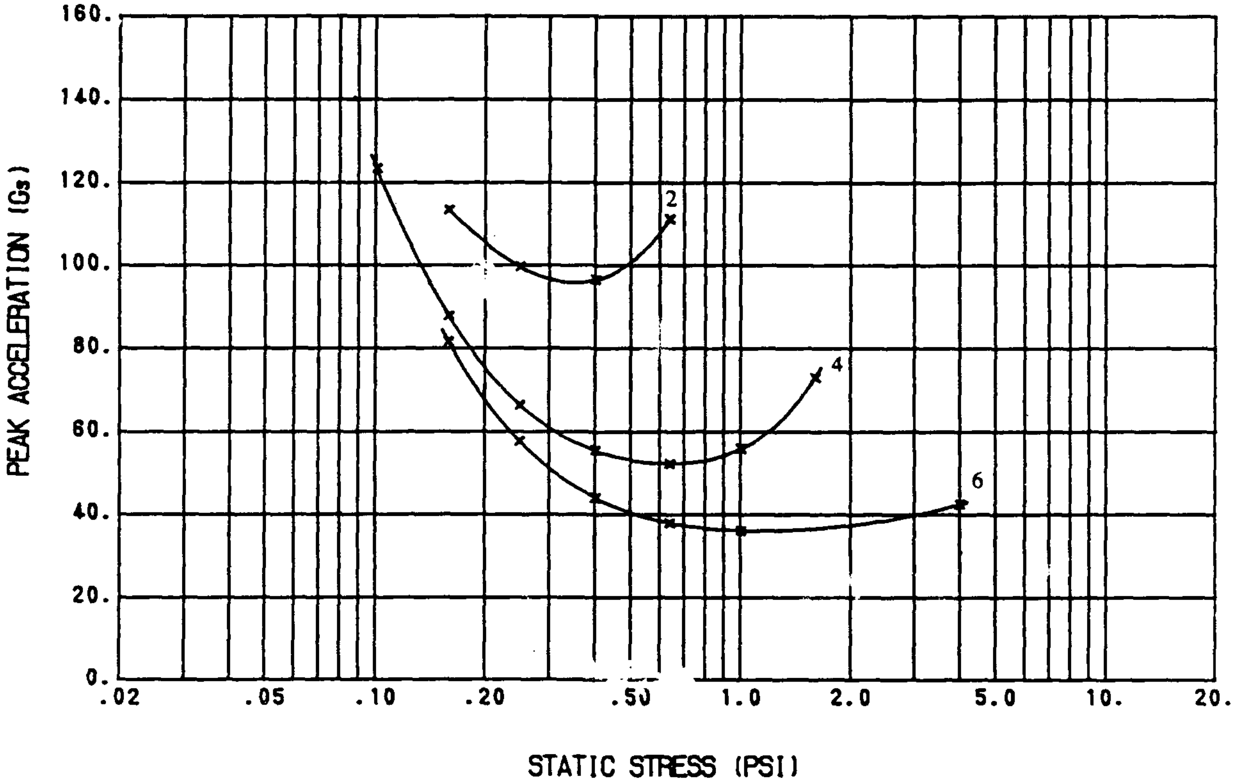

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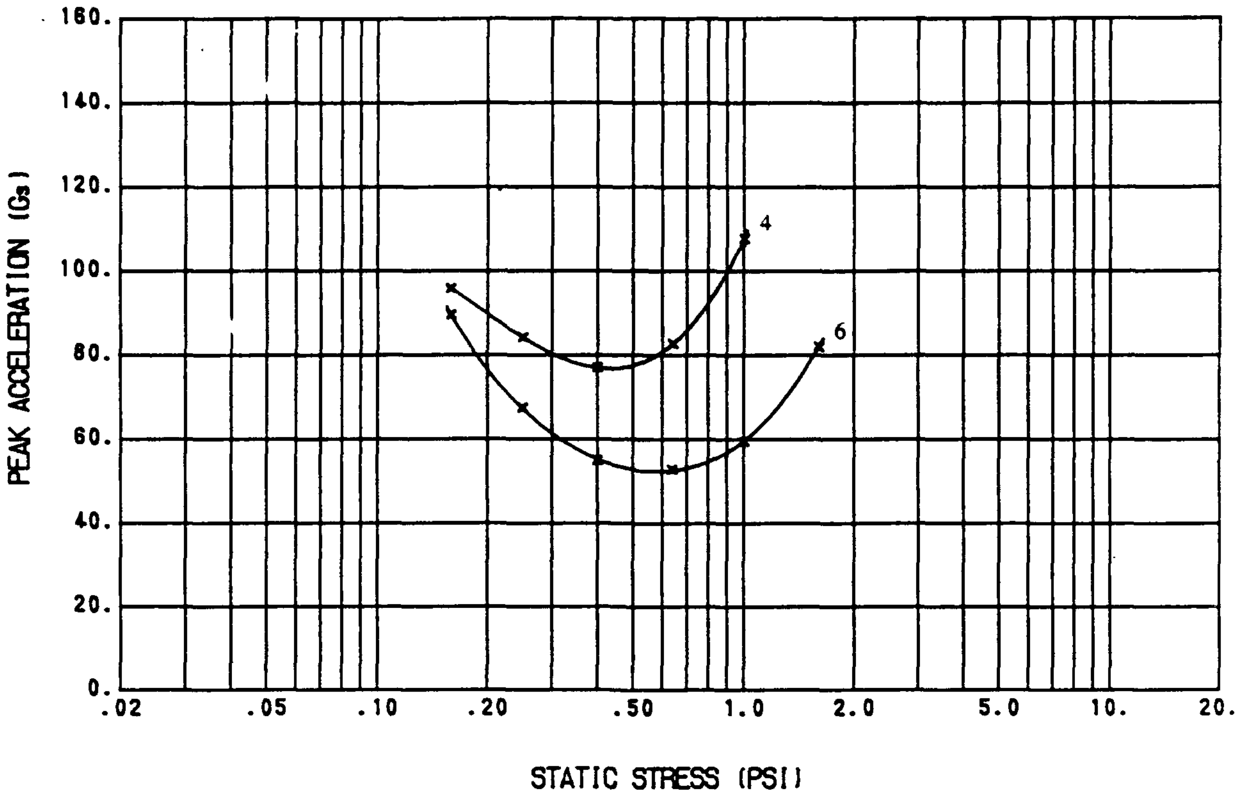

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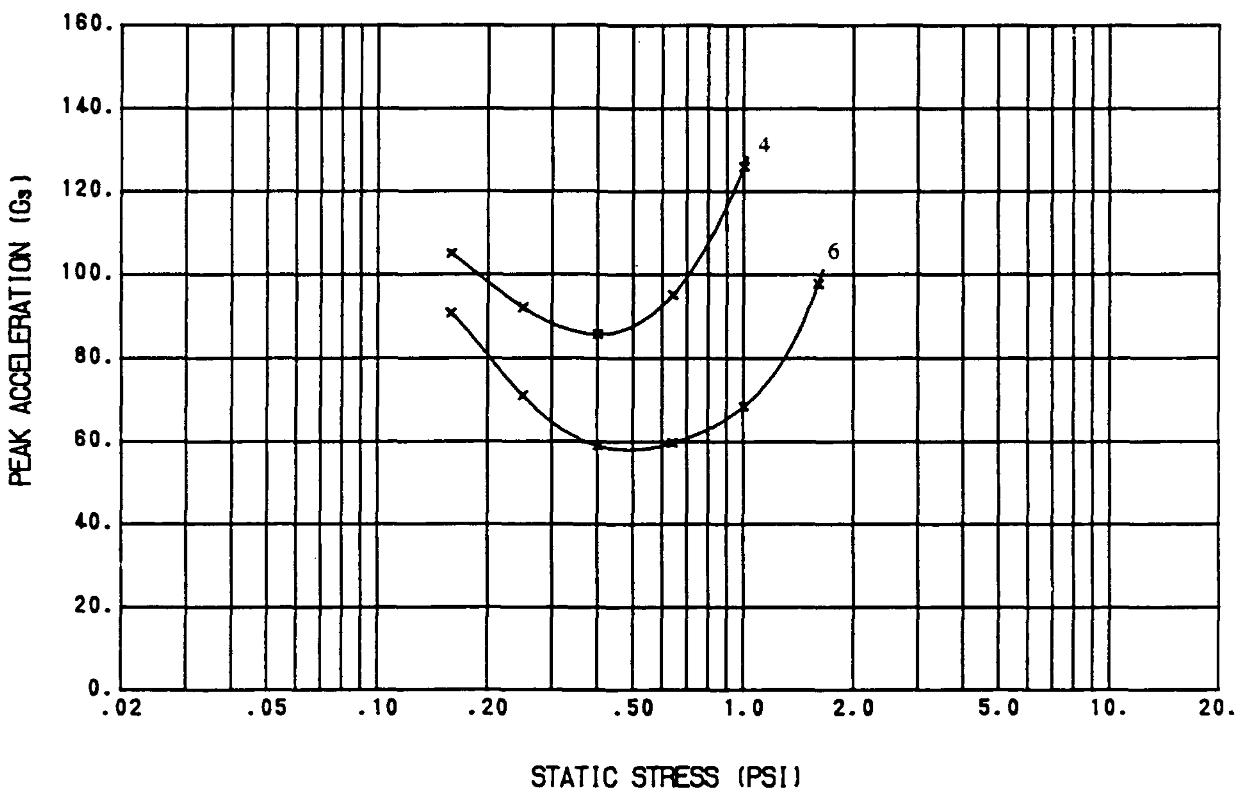

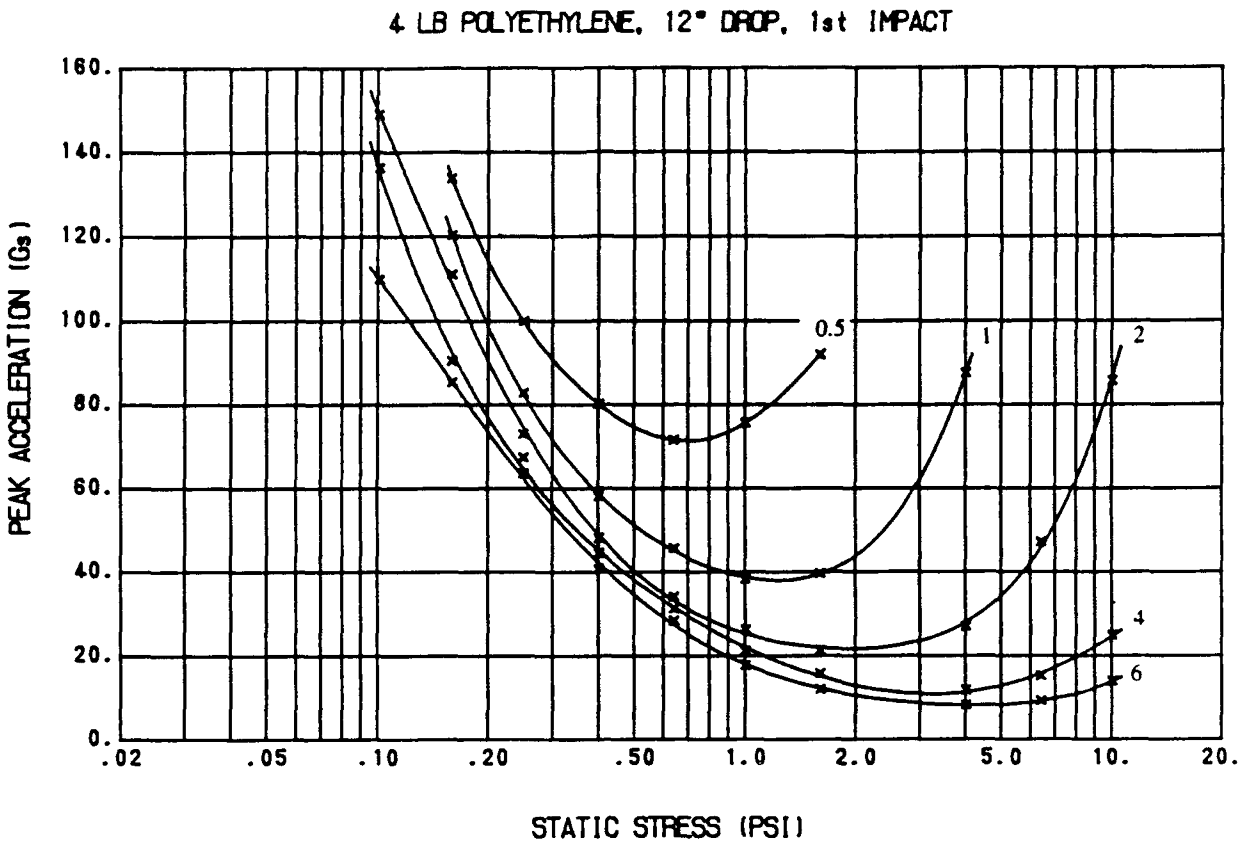
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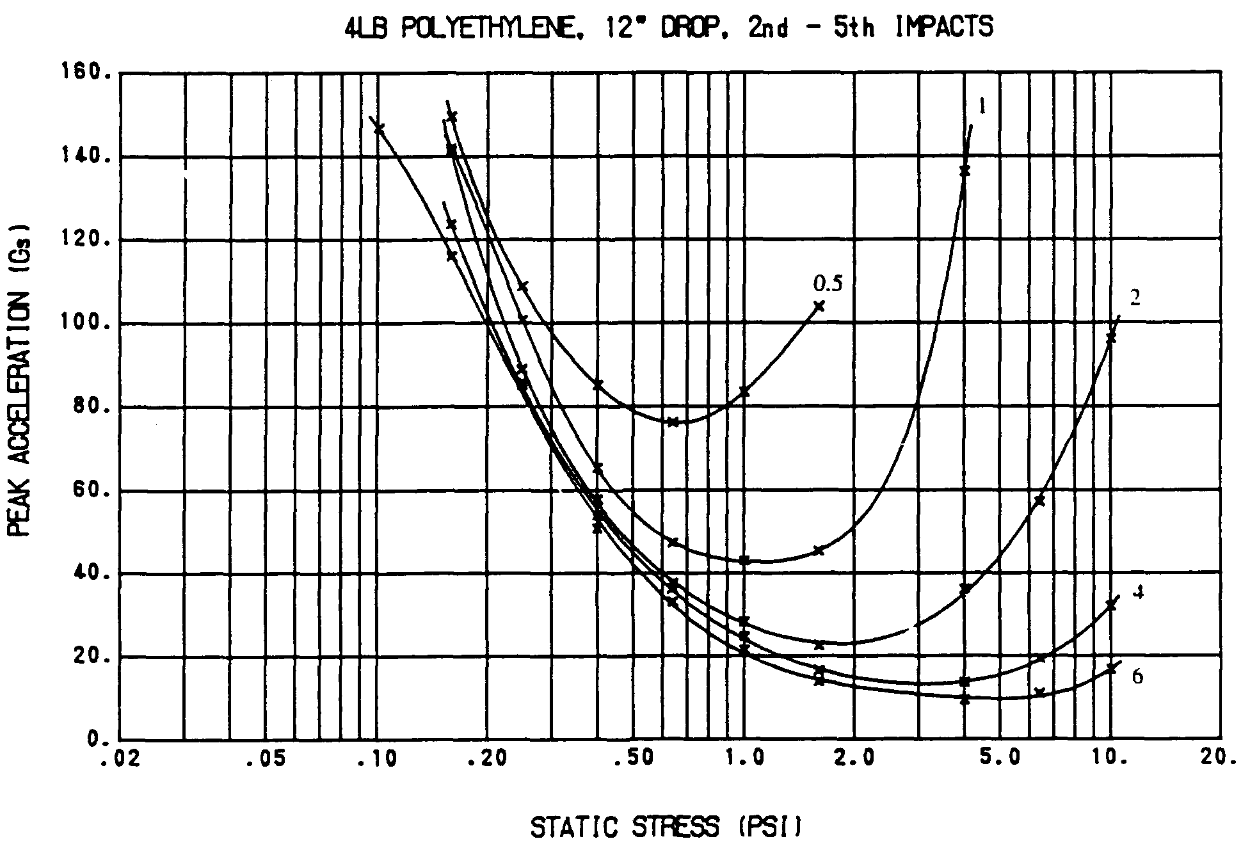
STATIC STRESS (PSI)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STATIC STRESS (PSI)

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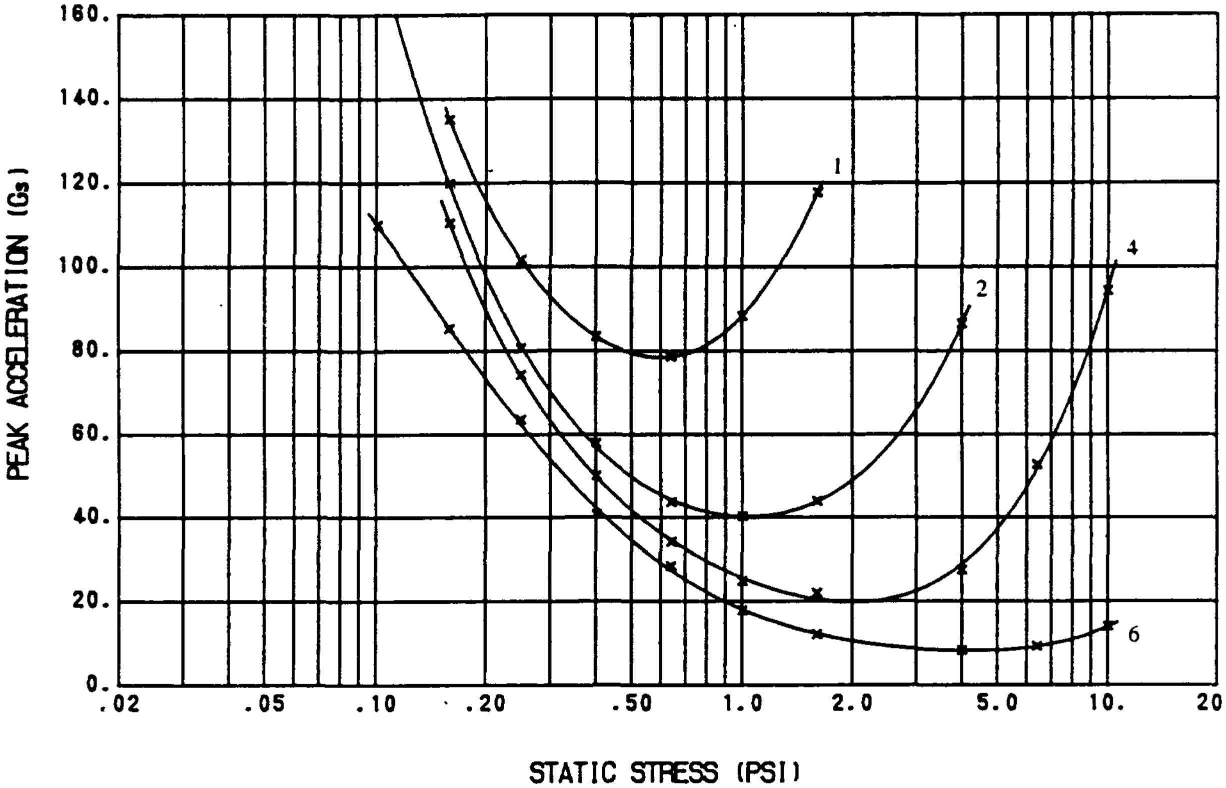

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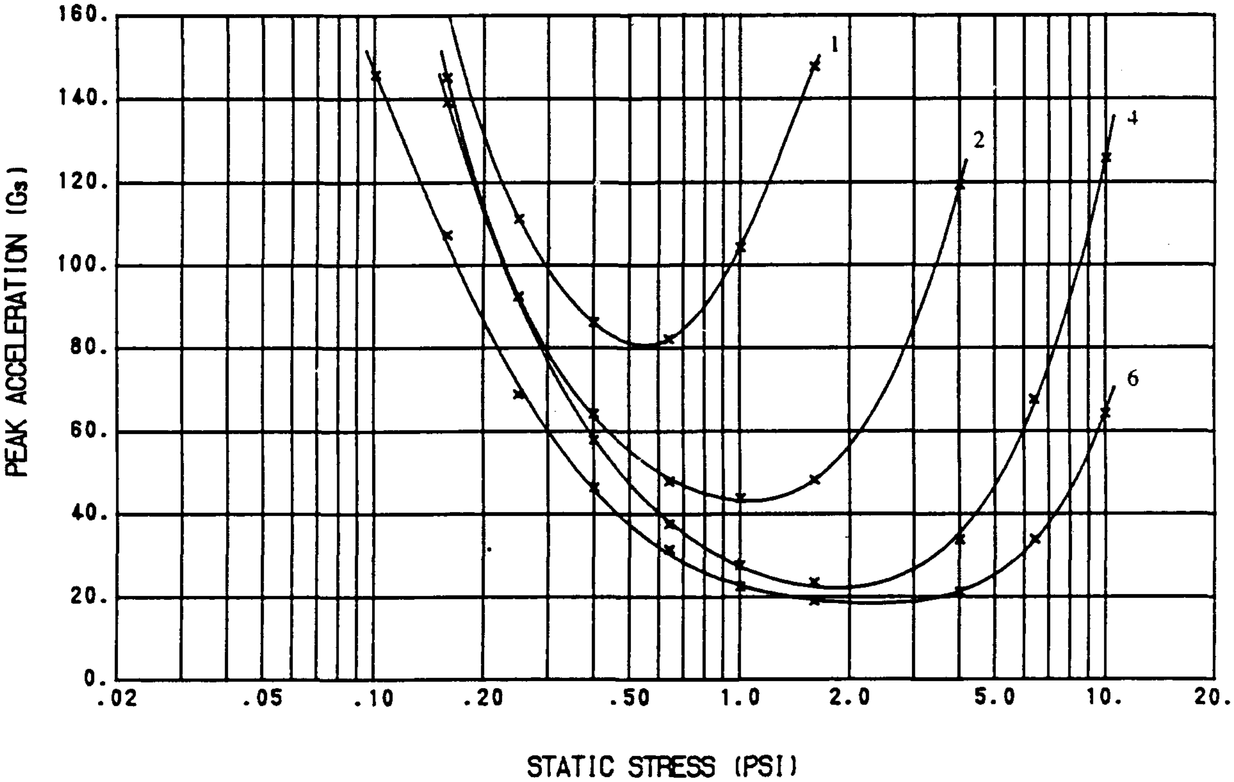

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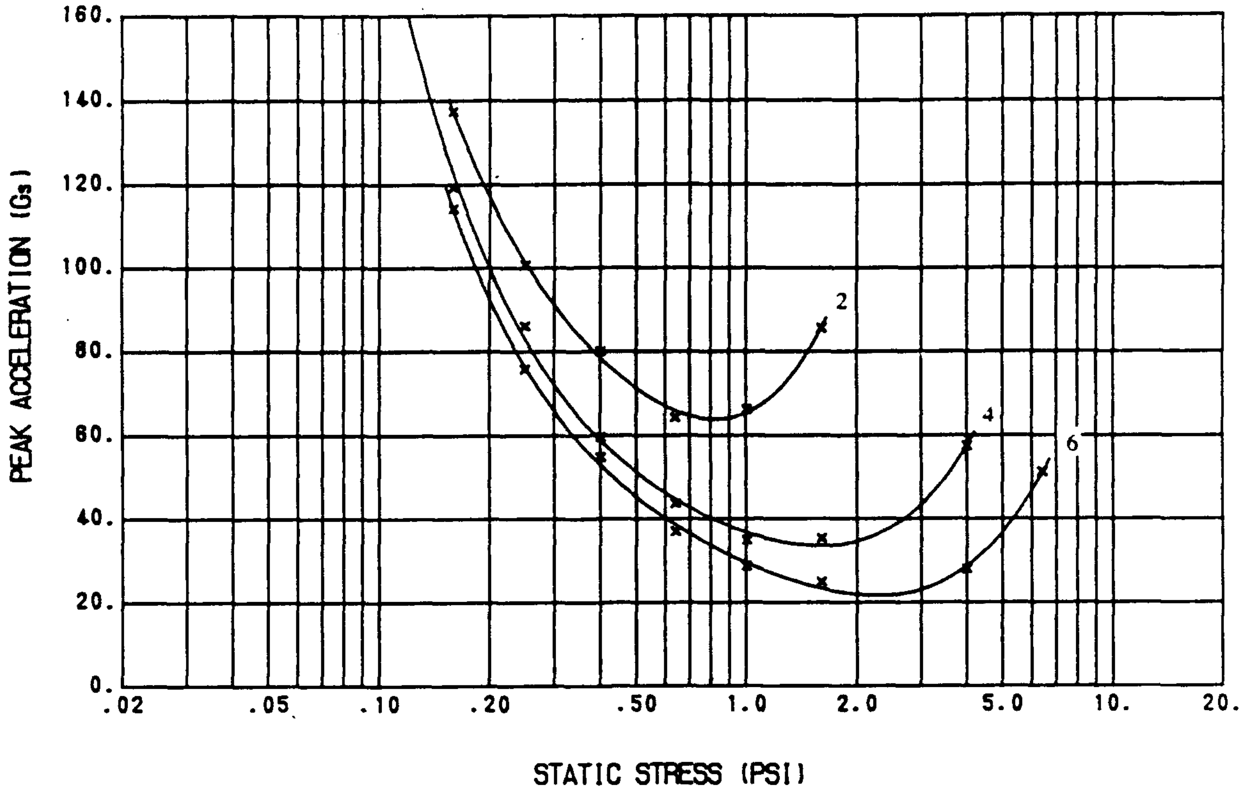

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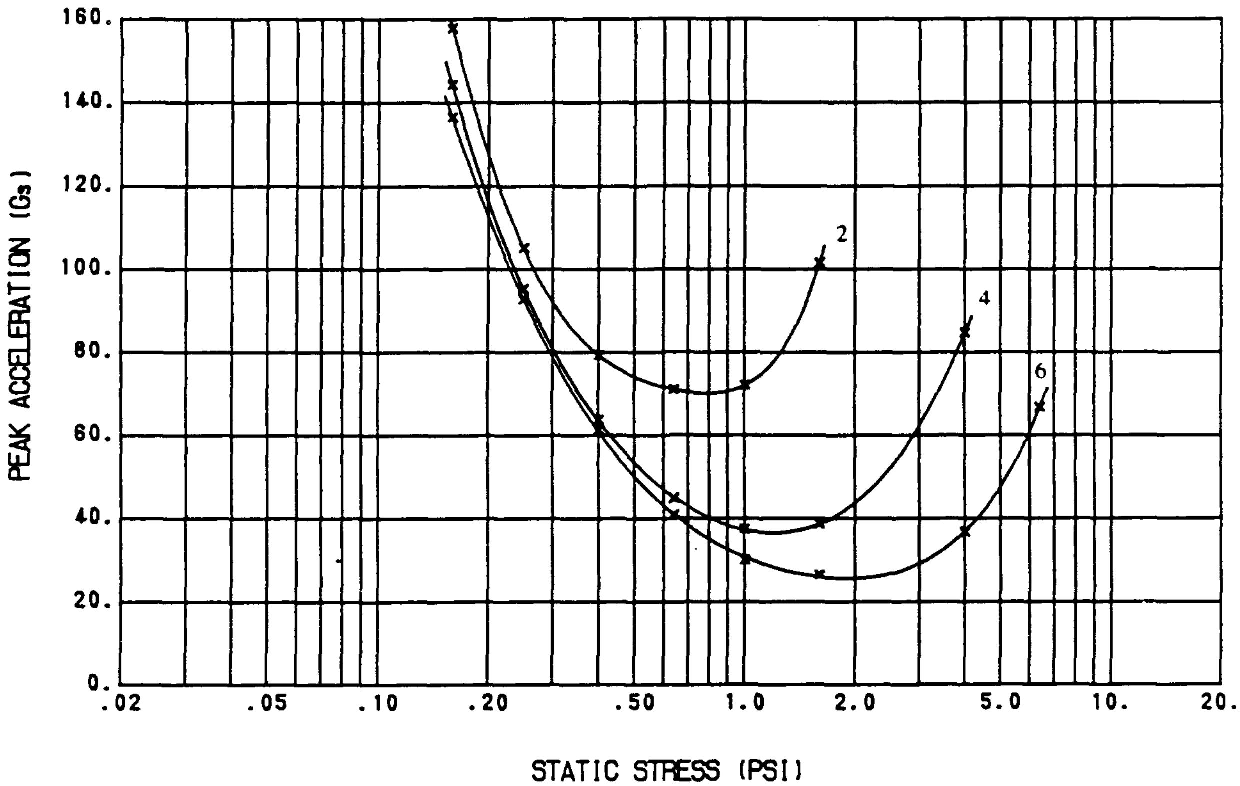

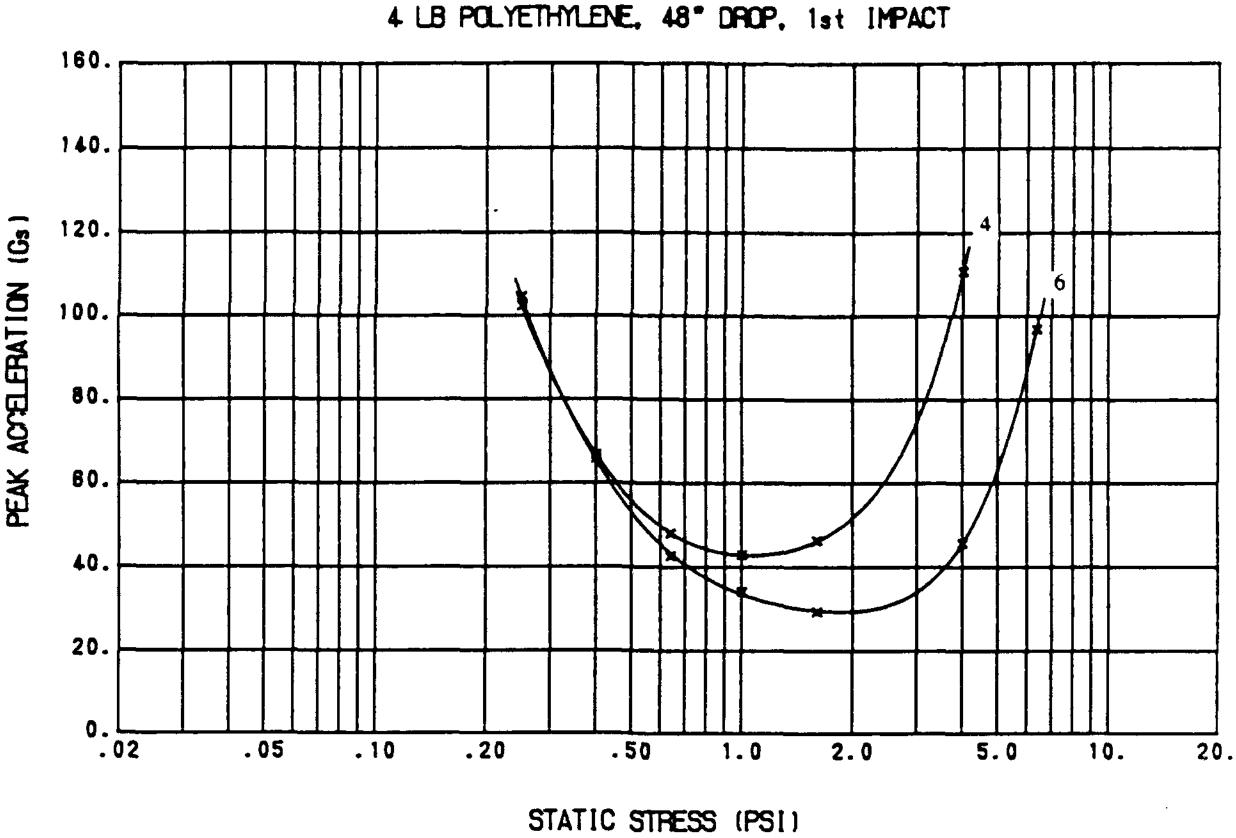
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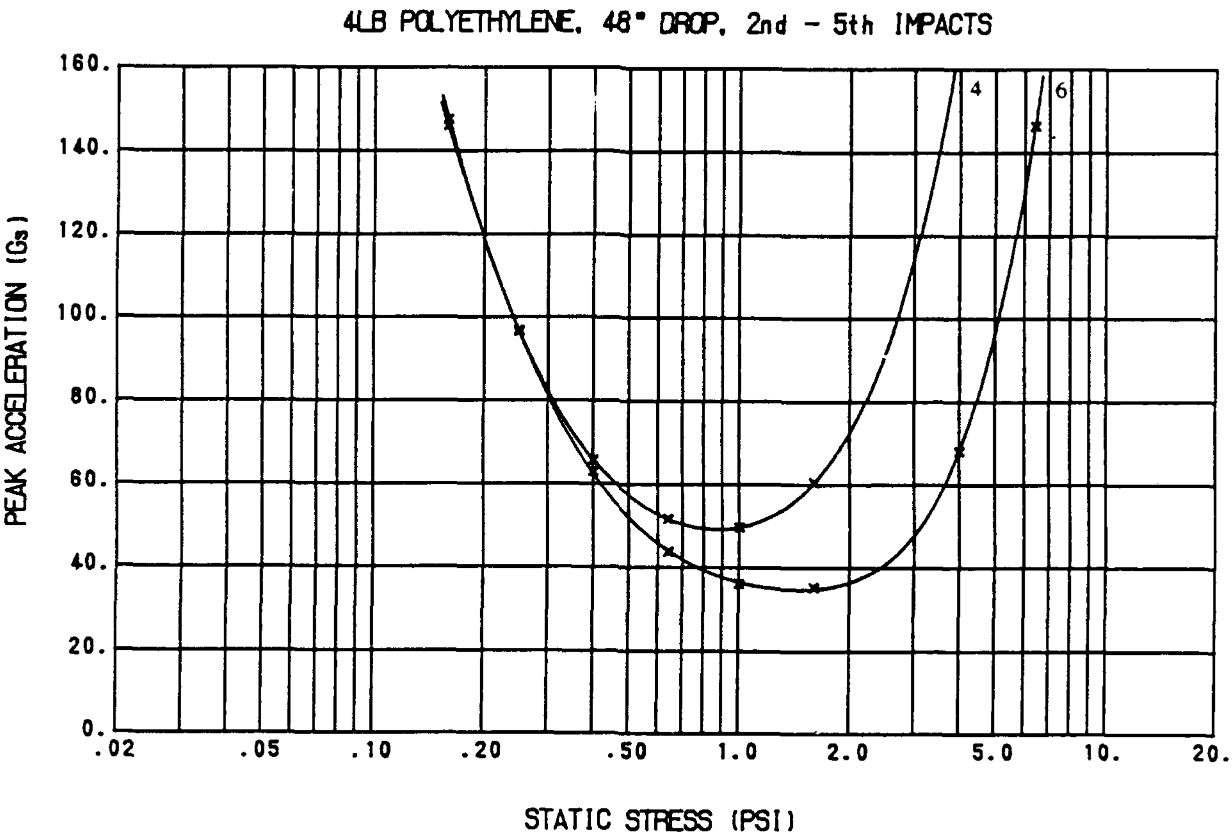
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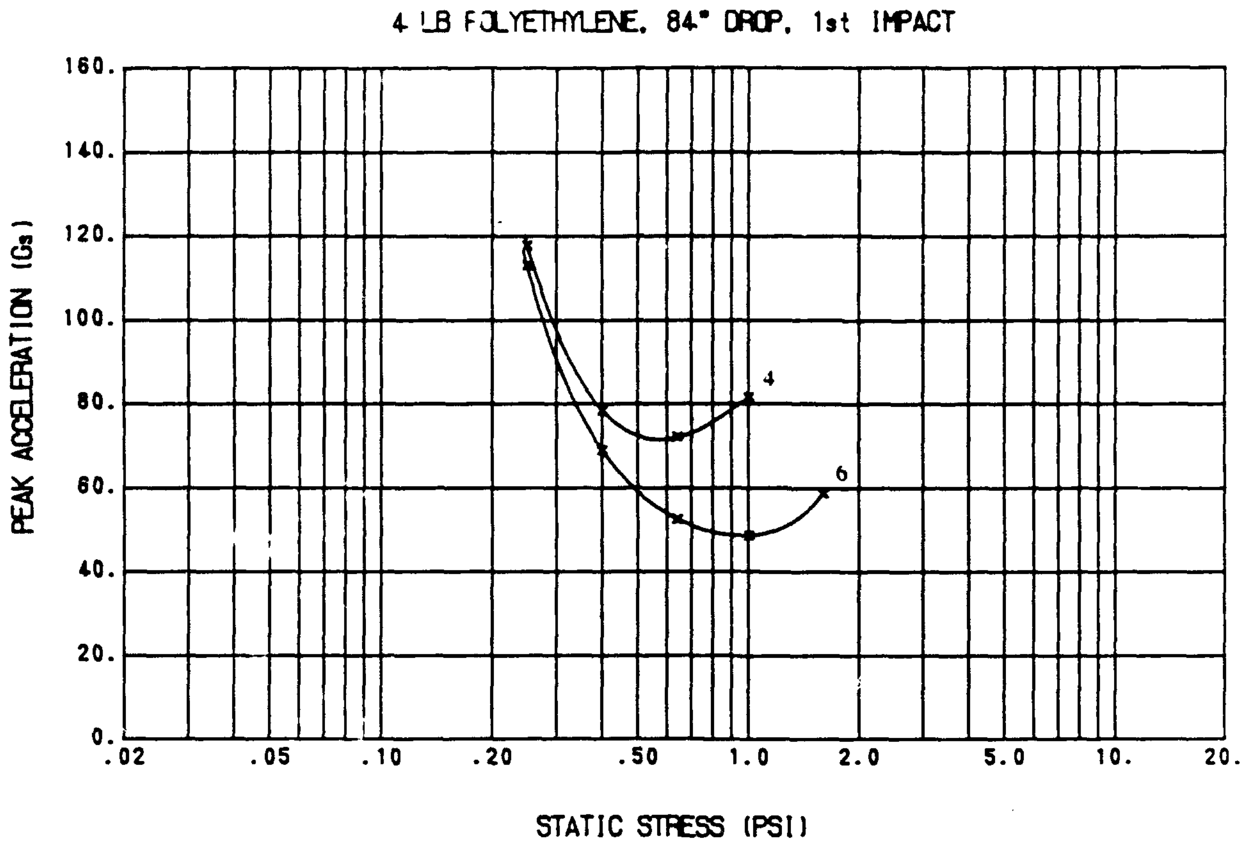
STATIC STRESS (PSI)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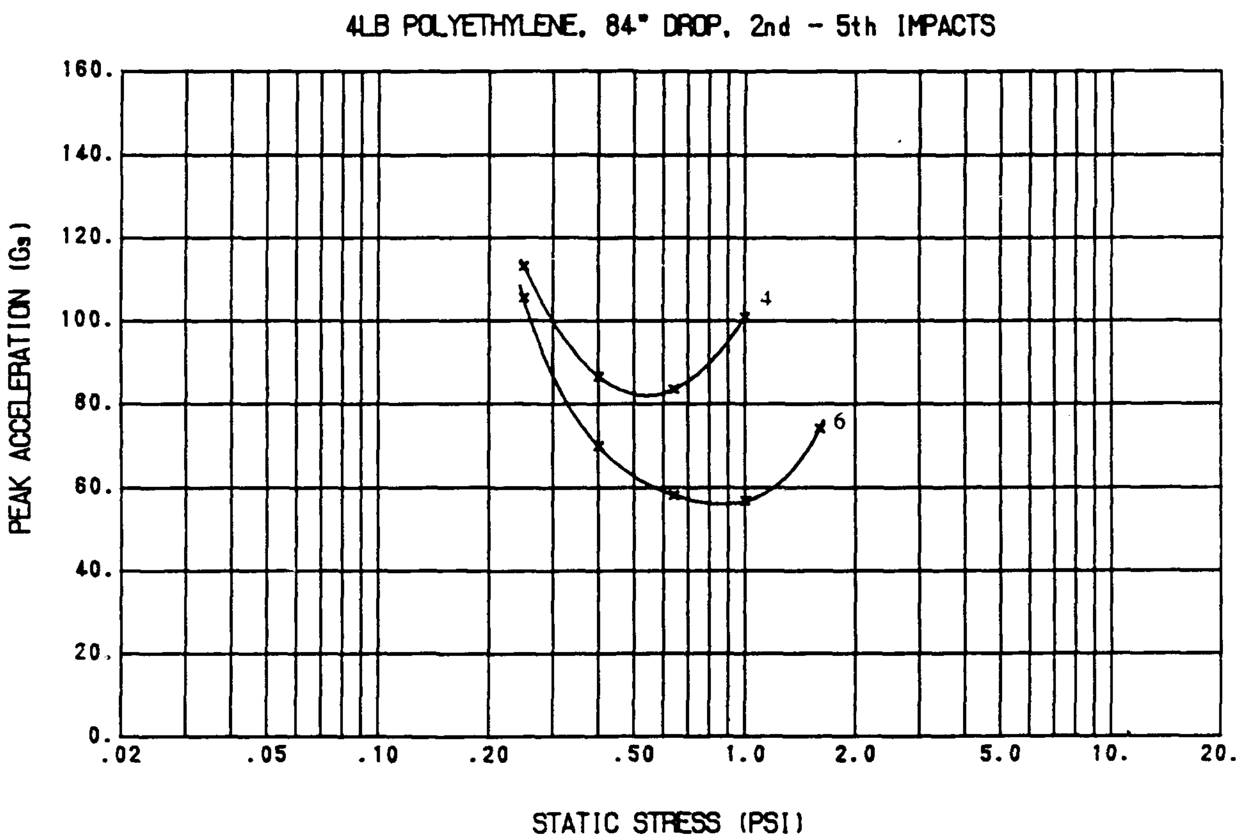
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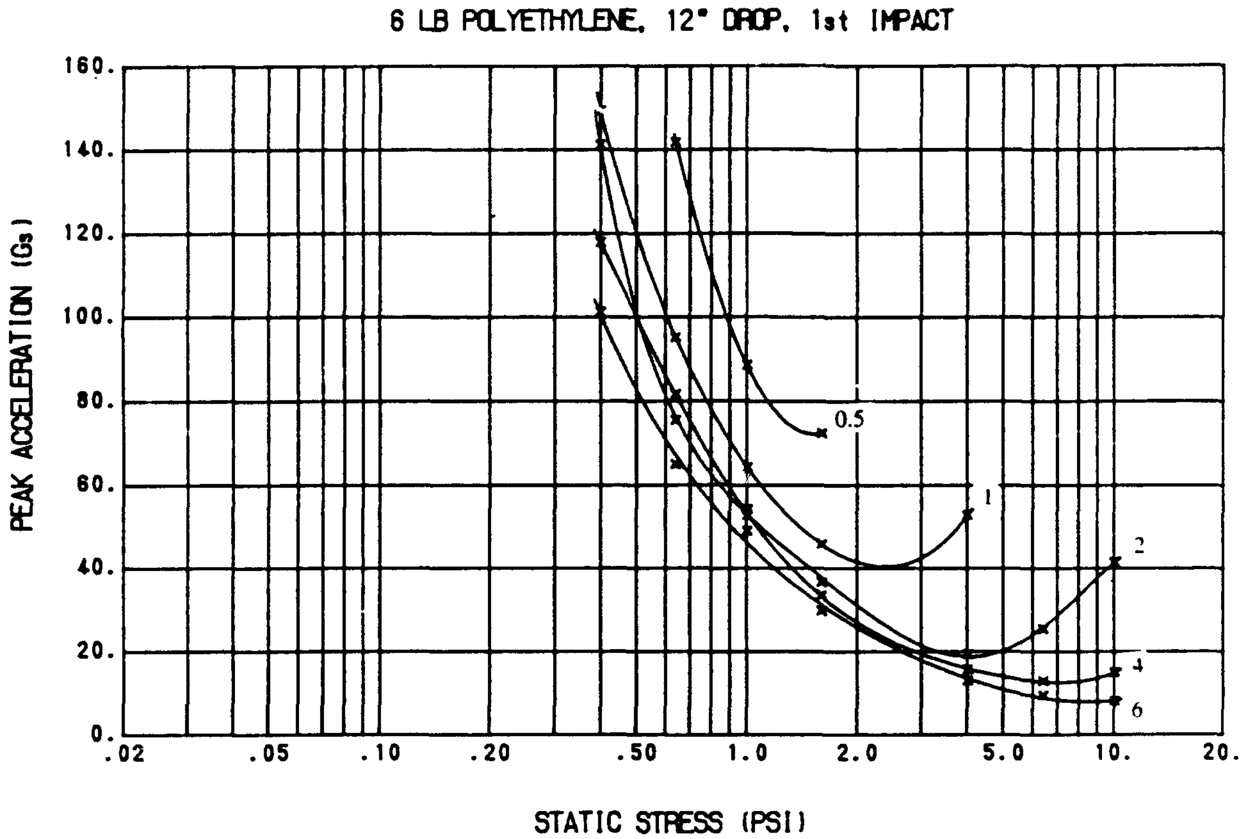
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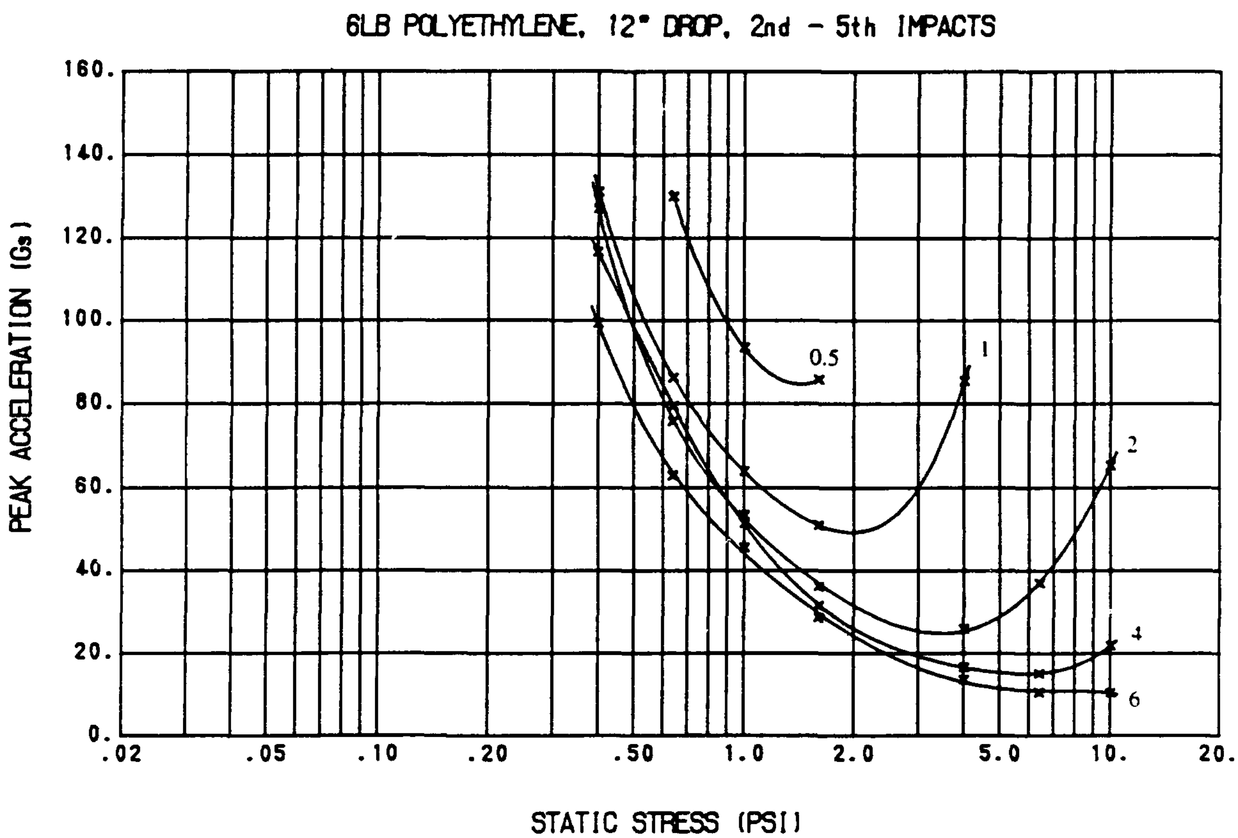
STATIC STRESS (PSI)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PEAK ACCELERATION (Gs)
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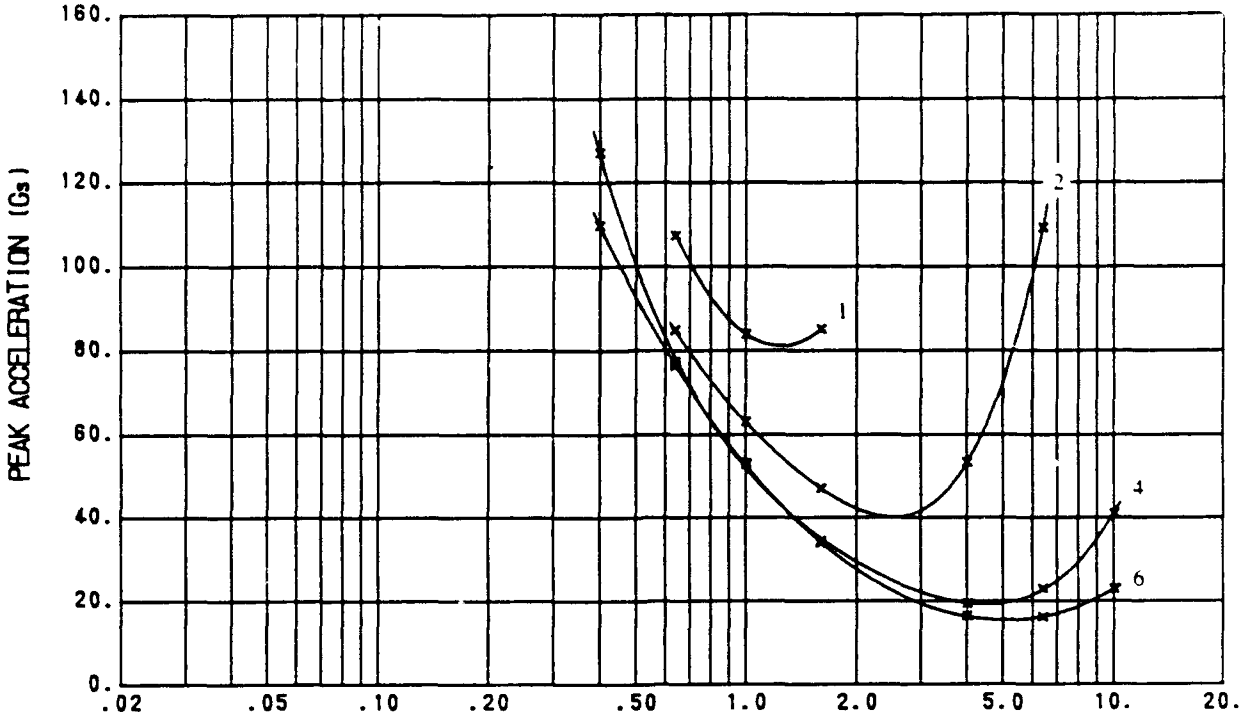
STATIC STRESS (PSI)

6 LB POLYETHYLENE, 24" DROP, 1st IMPACT



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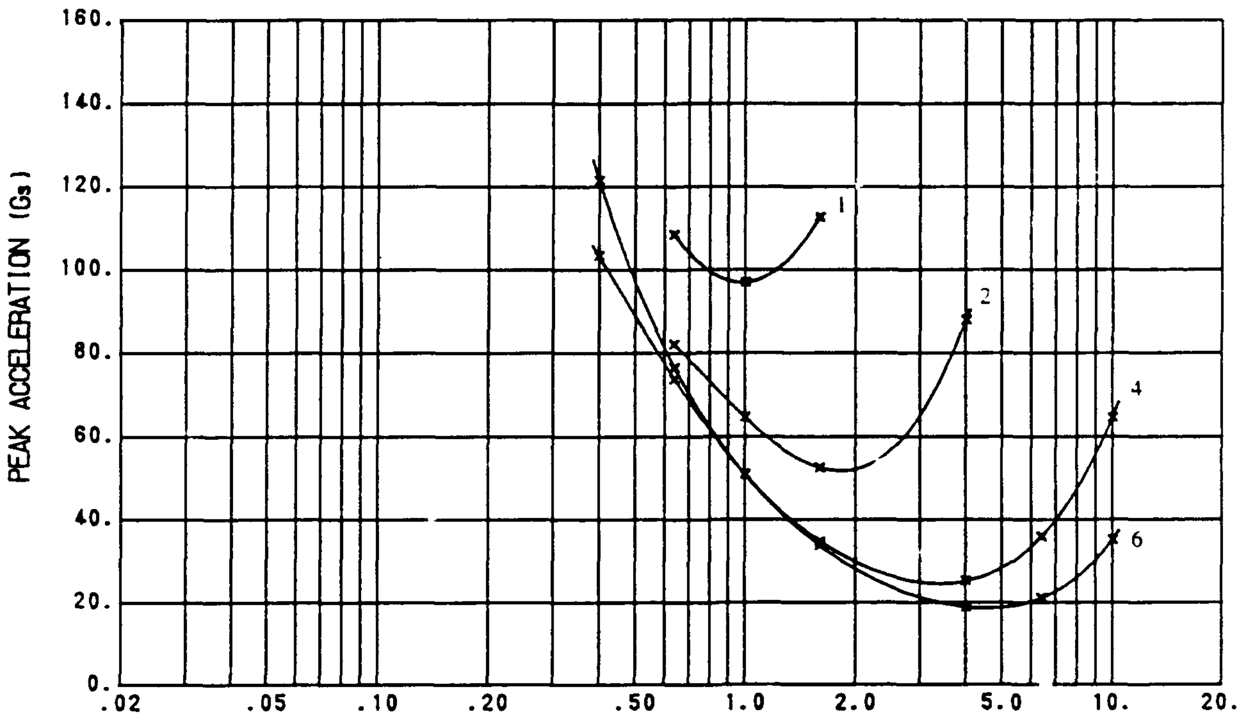

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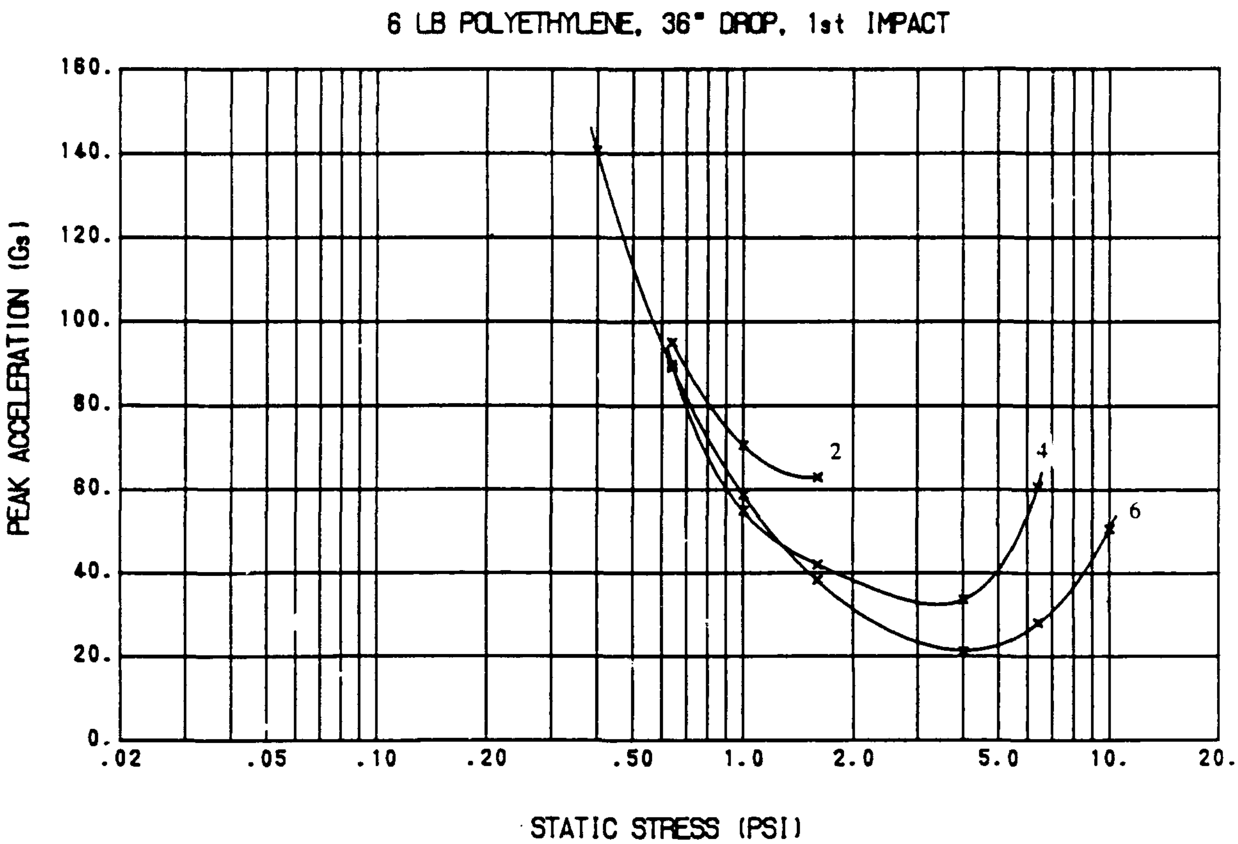
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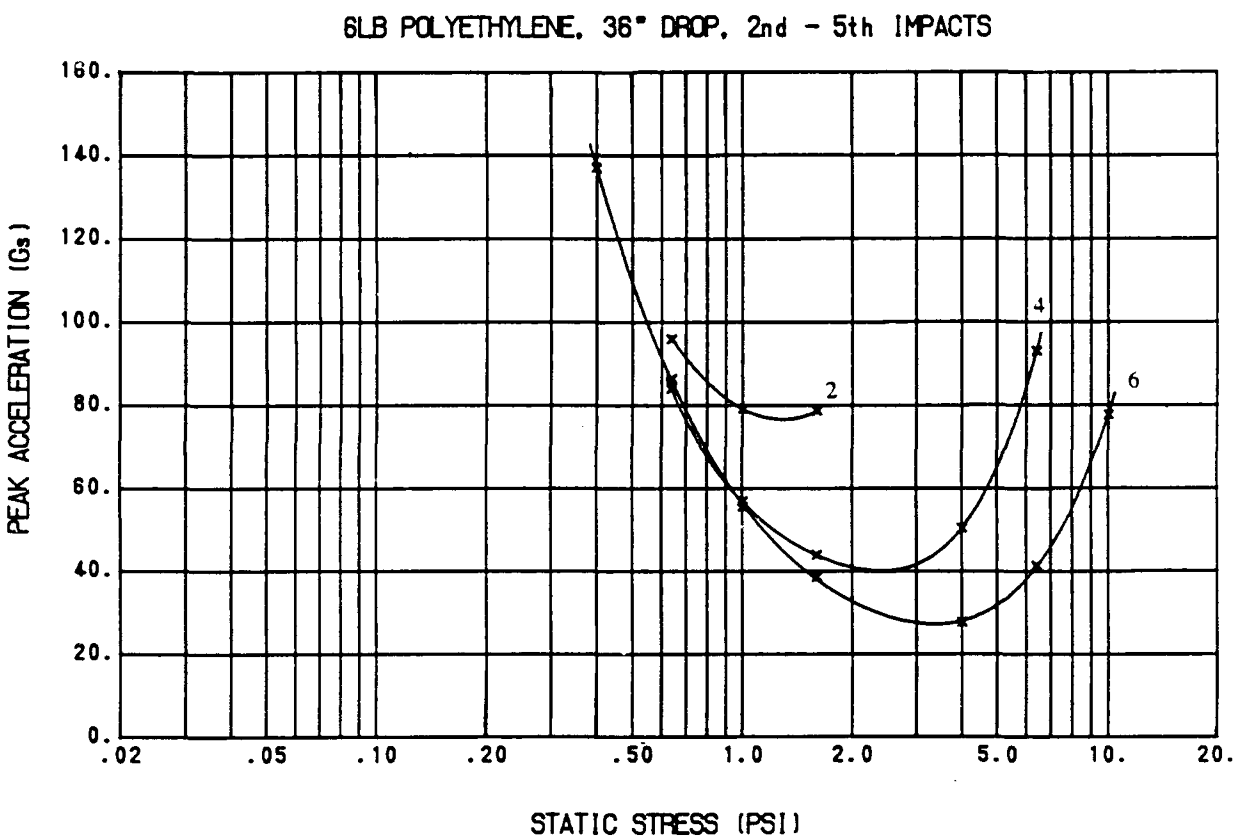
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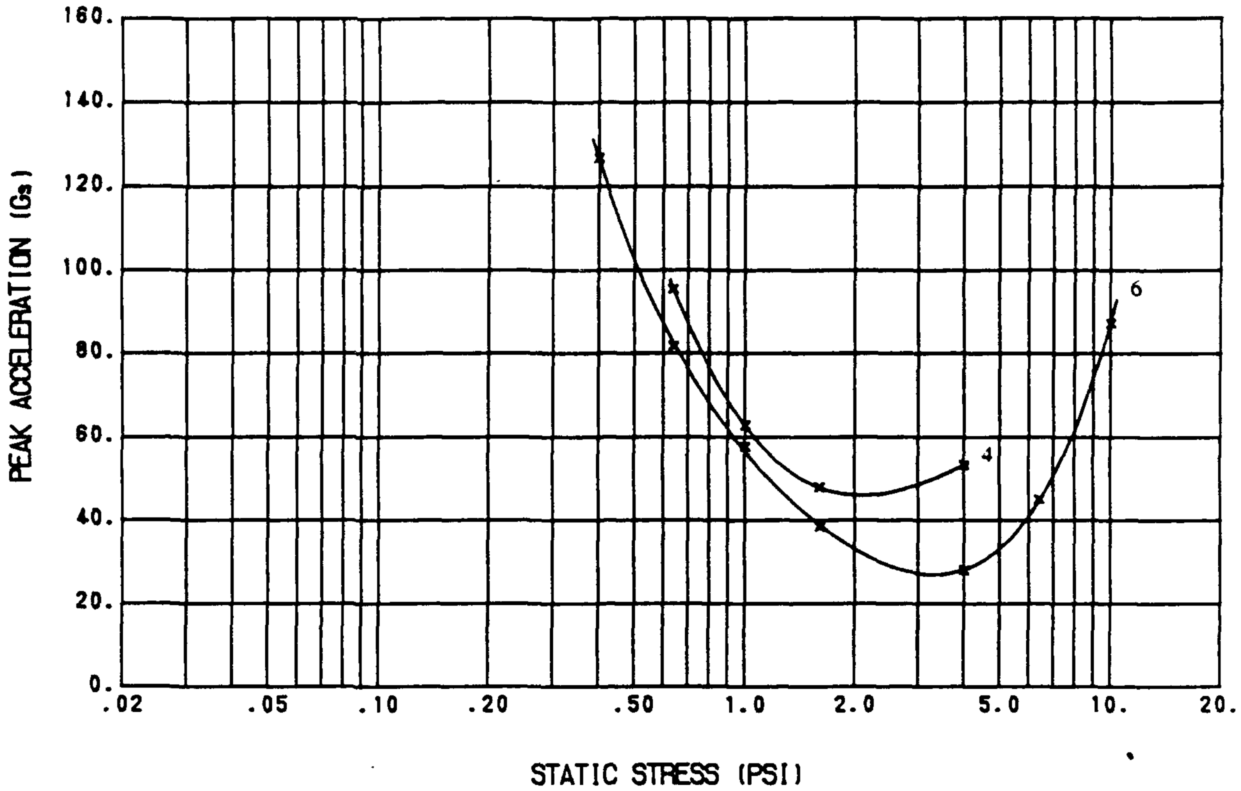
STATIC STRESS (PSI)

6 LB POLYETHYLENE, 48" DROP, 1st IMPACT



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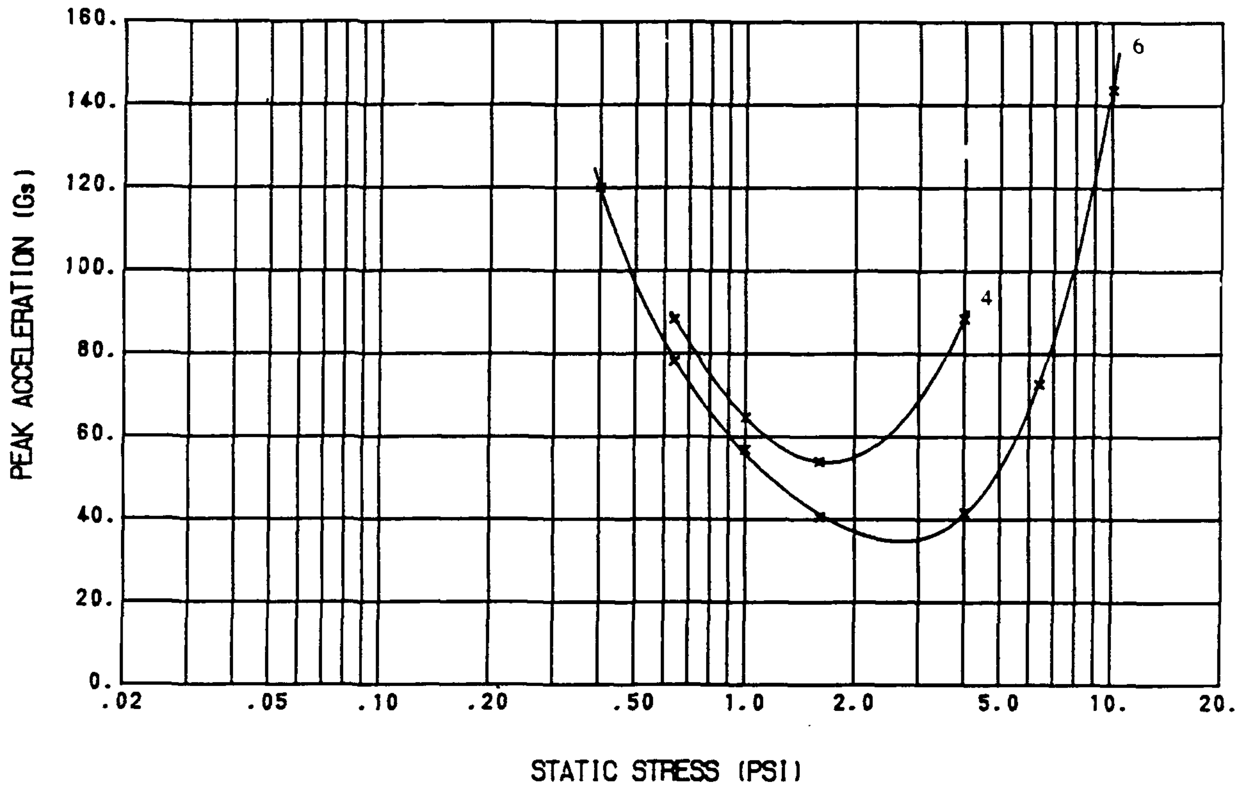

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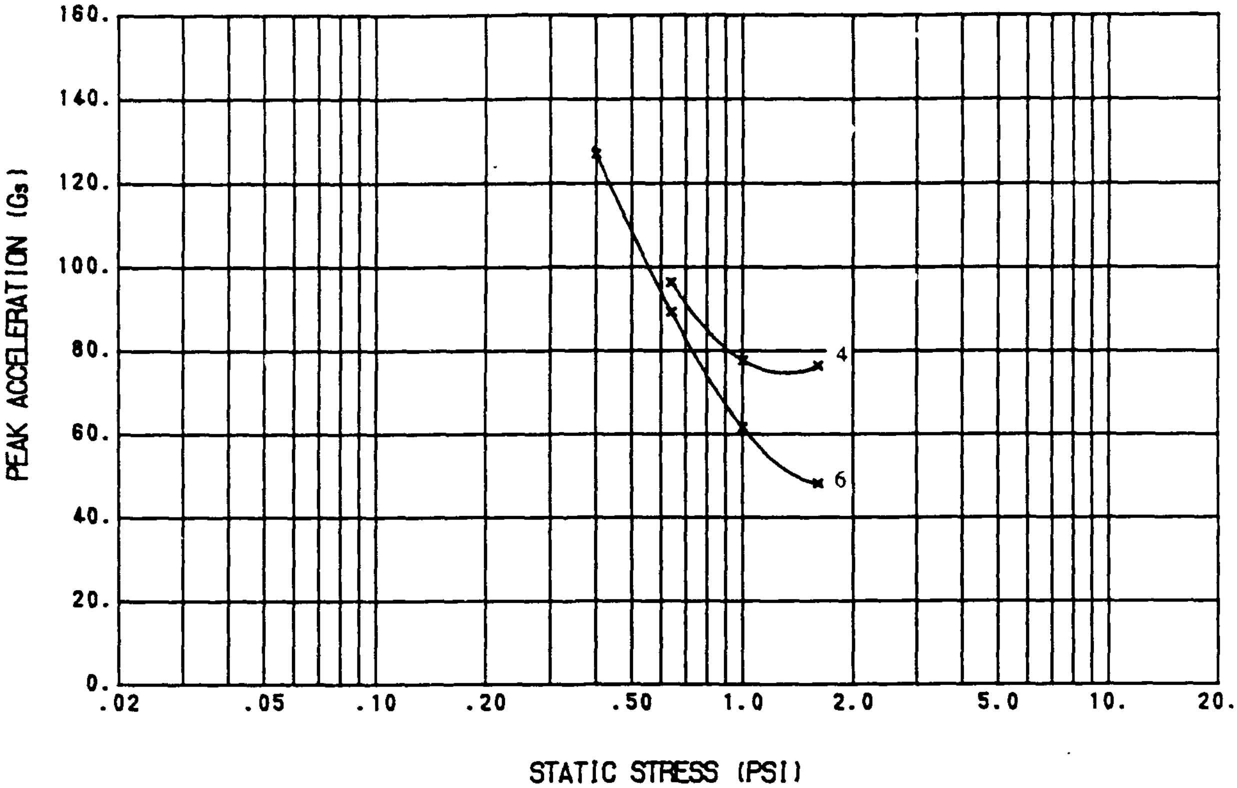

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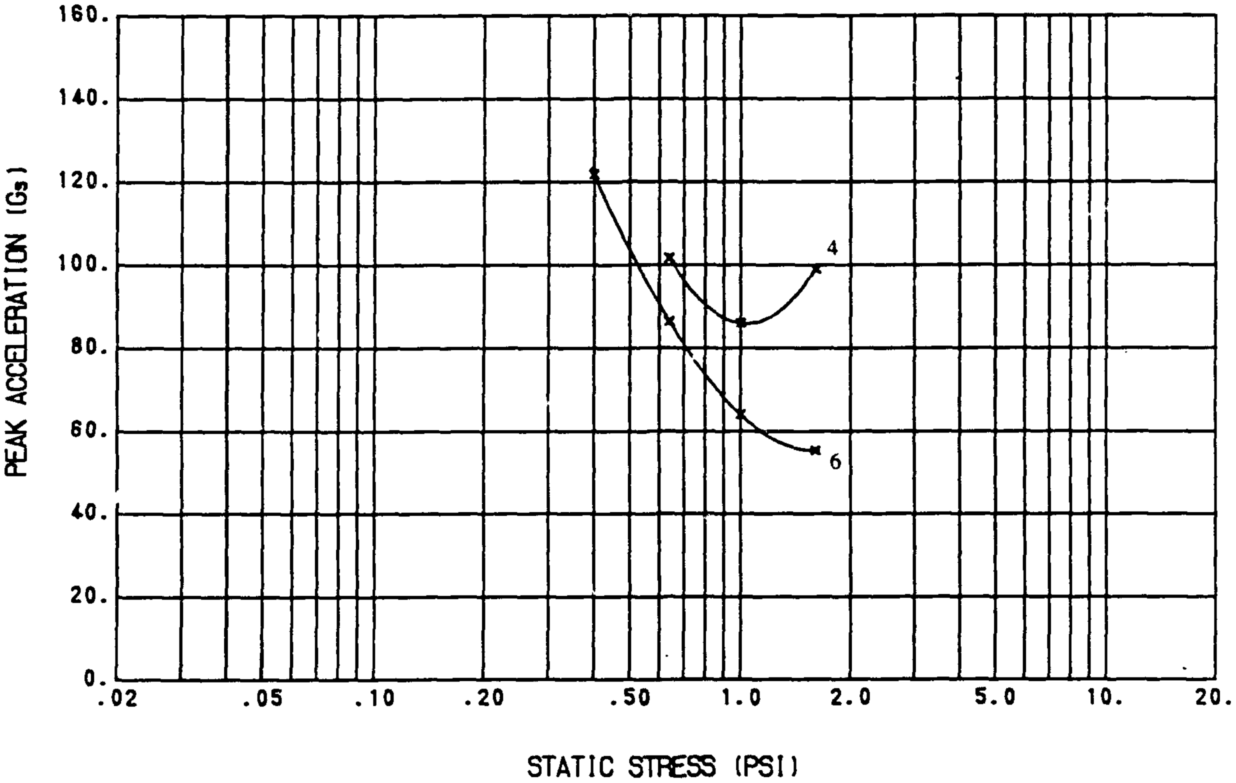

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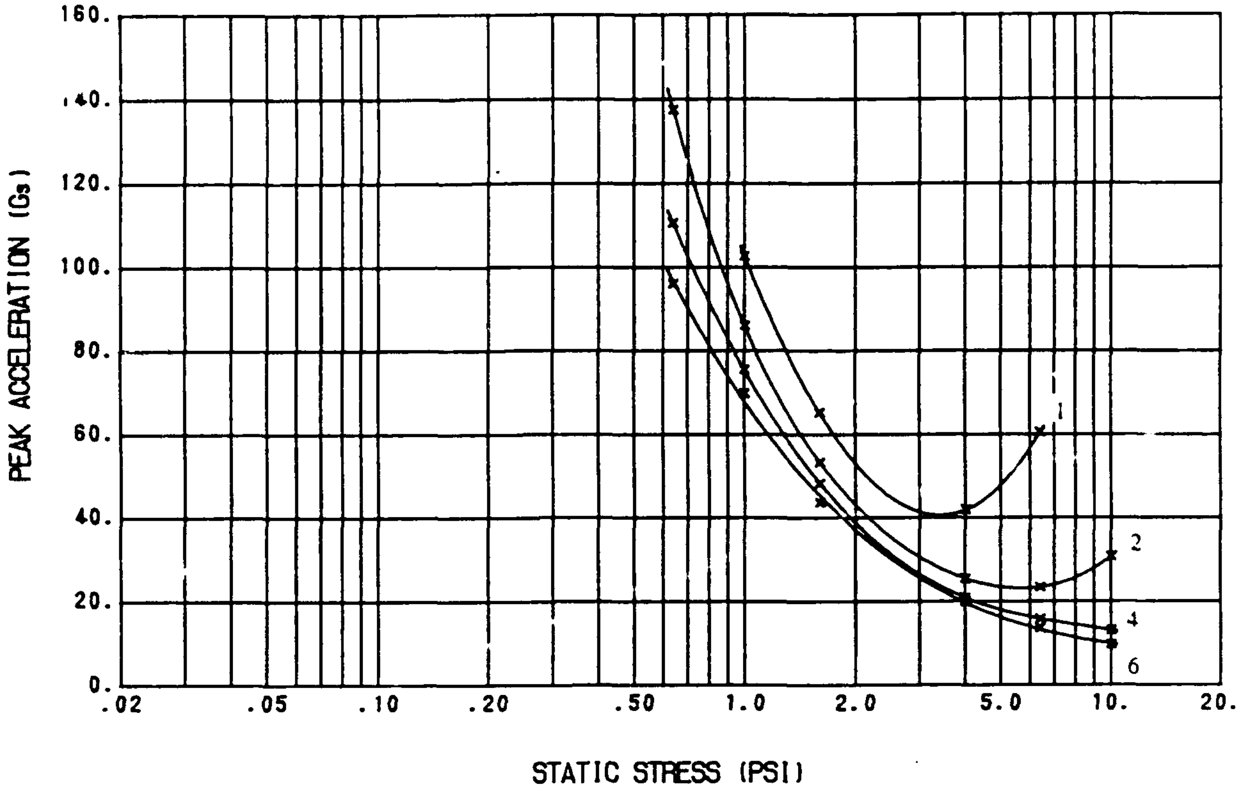

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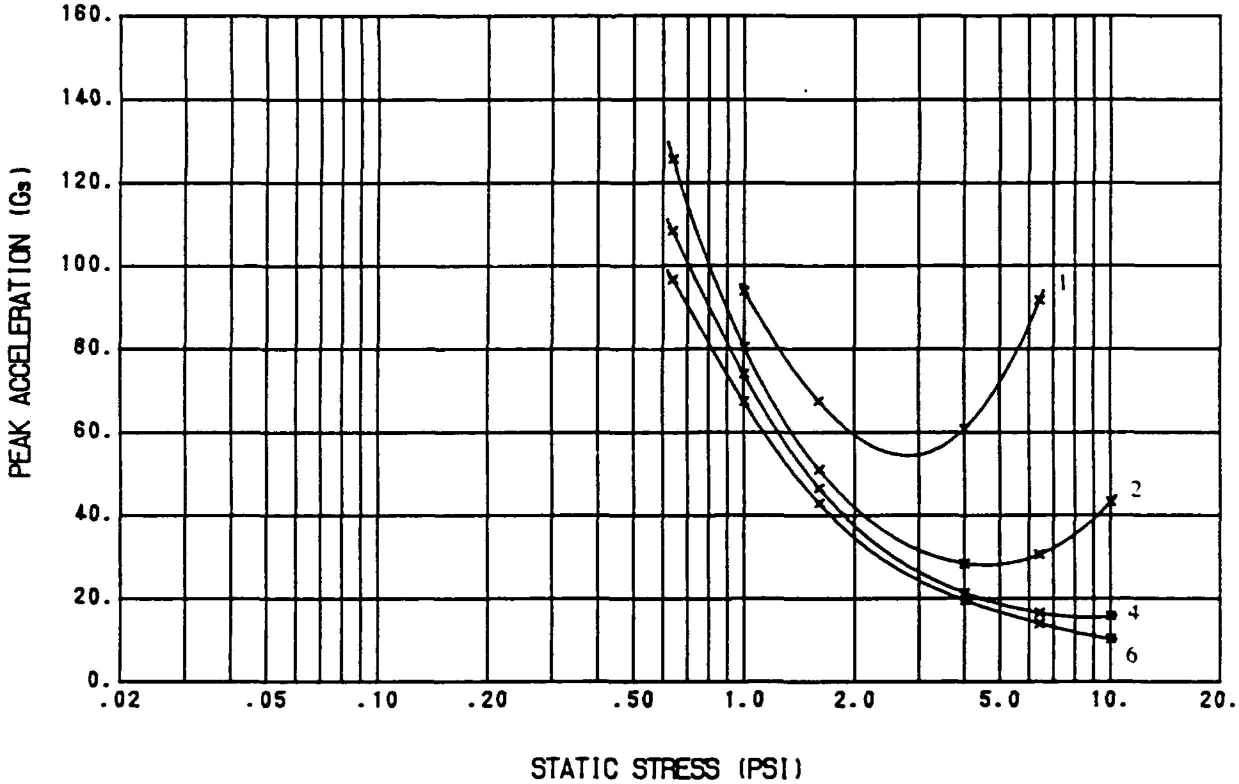

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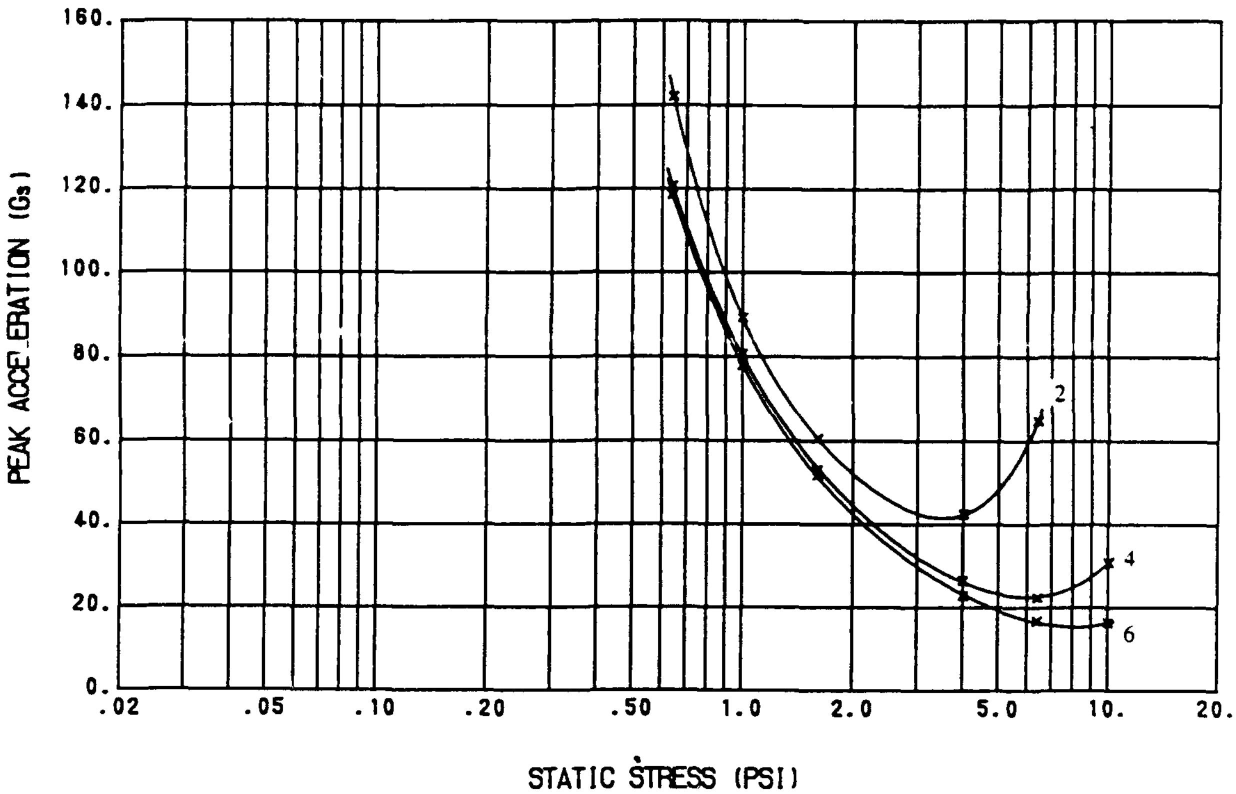

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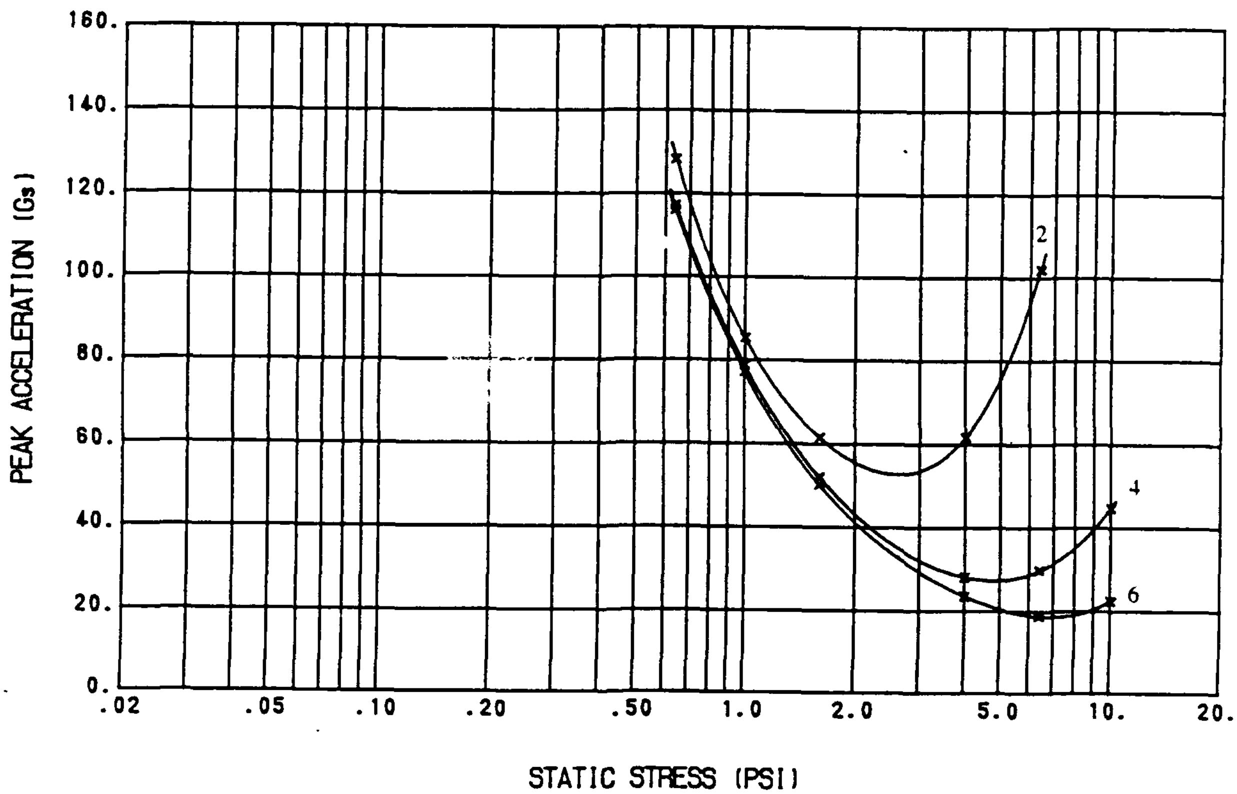

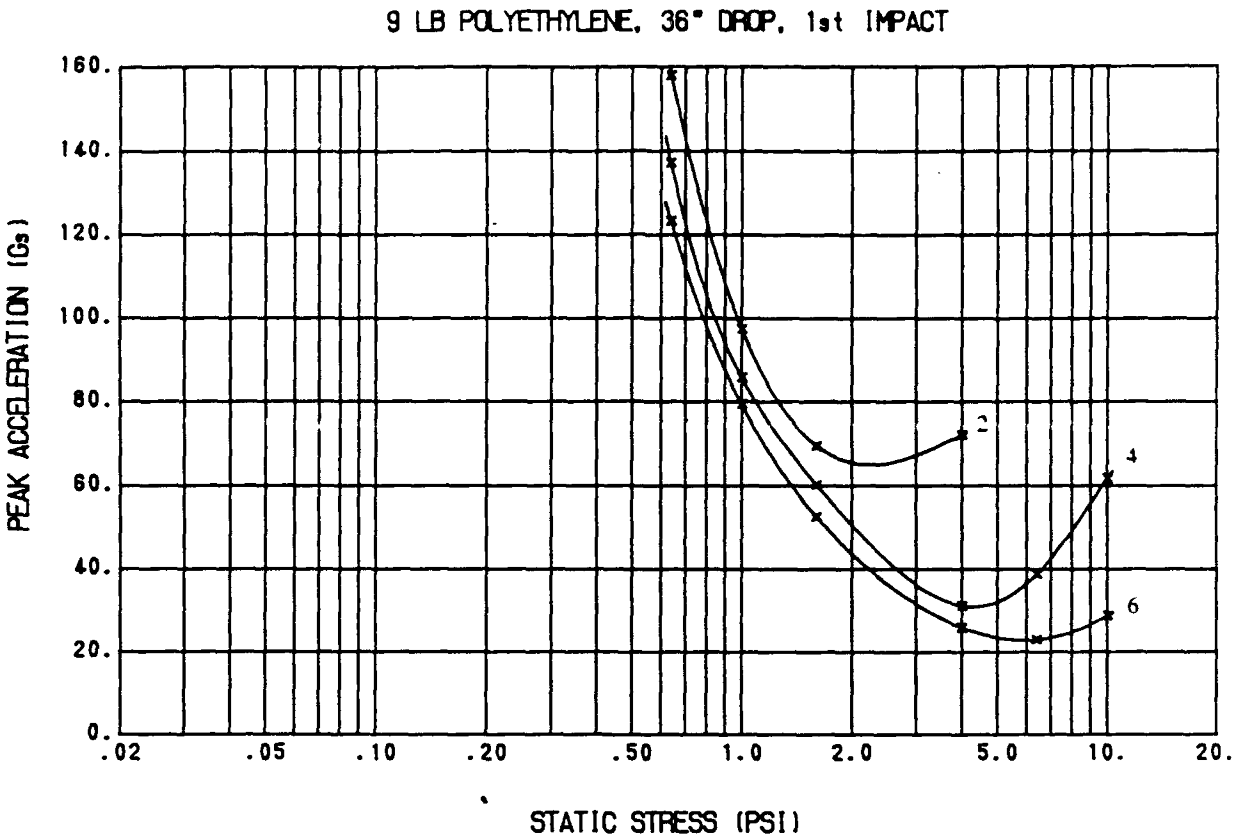
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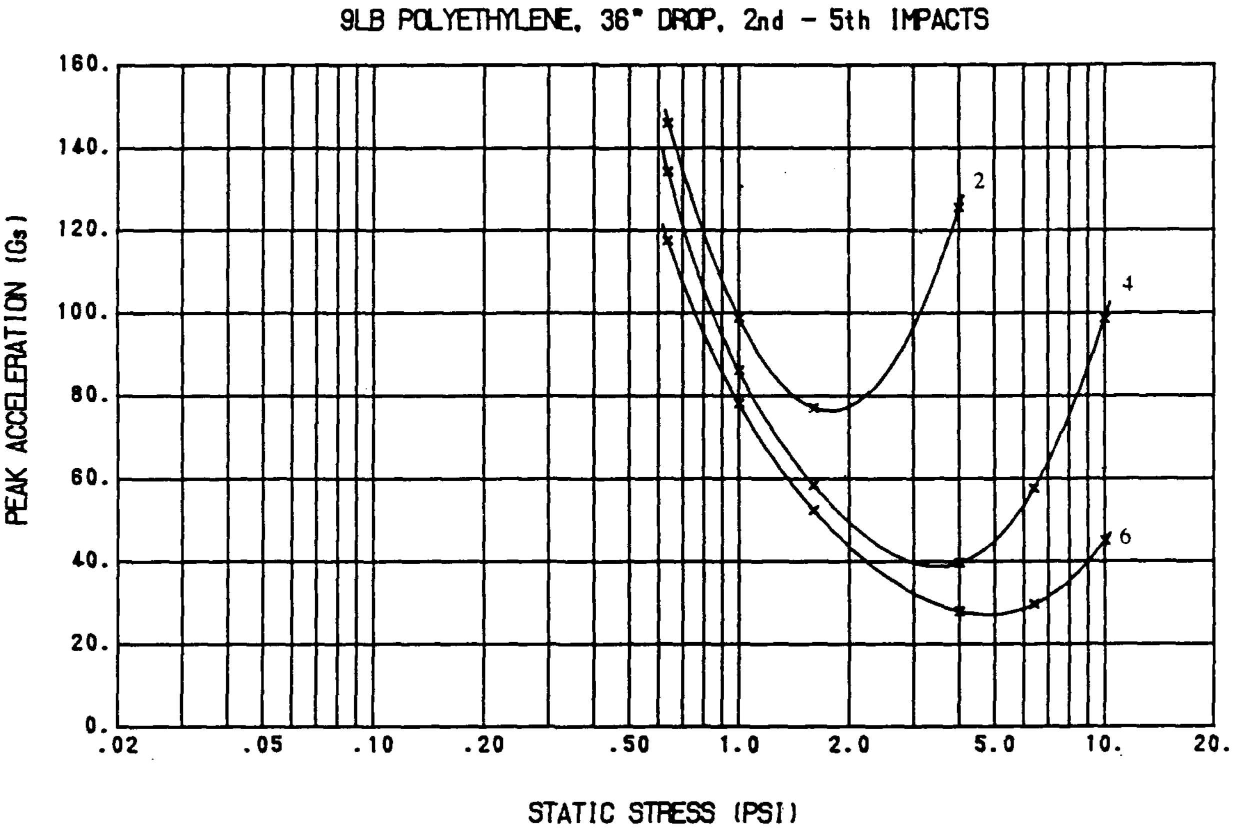
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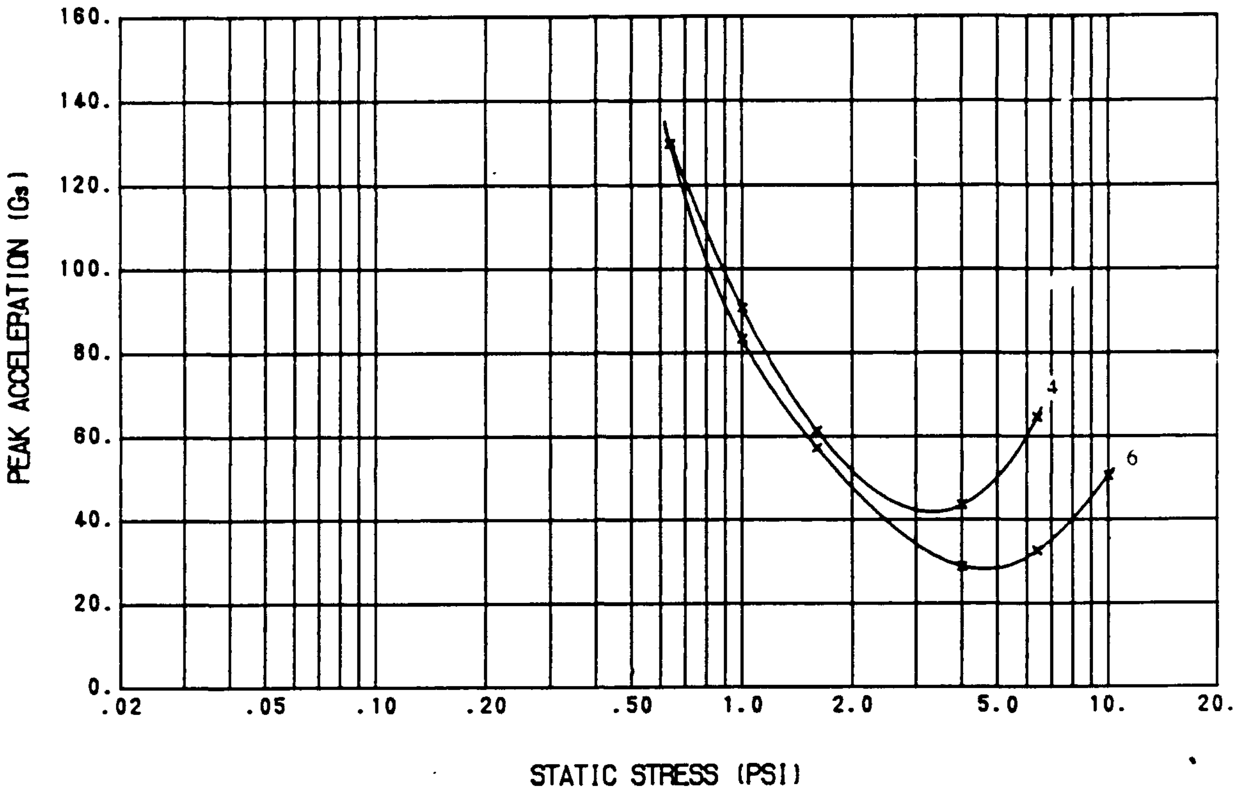
9 LB POLYETHYLENE, 48" DROP, 1st IMPACT



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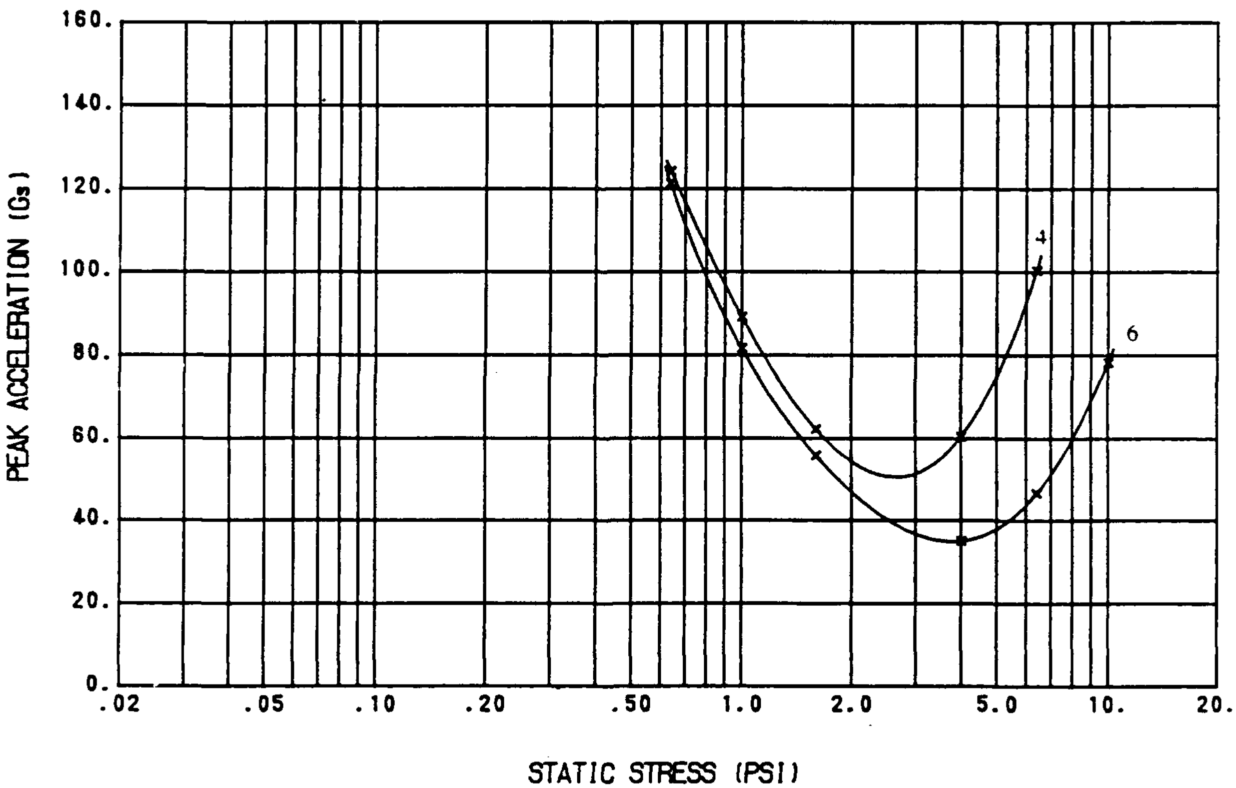

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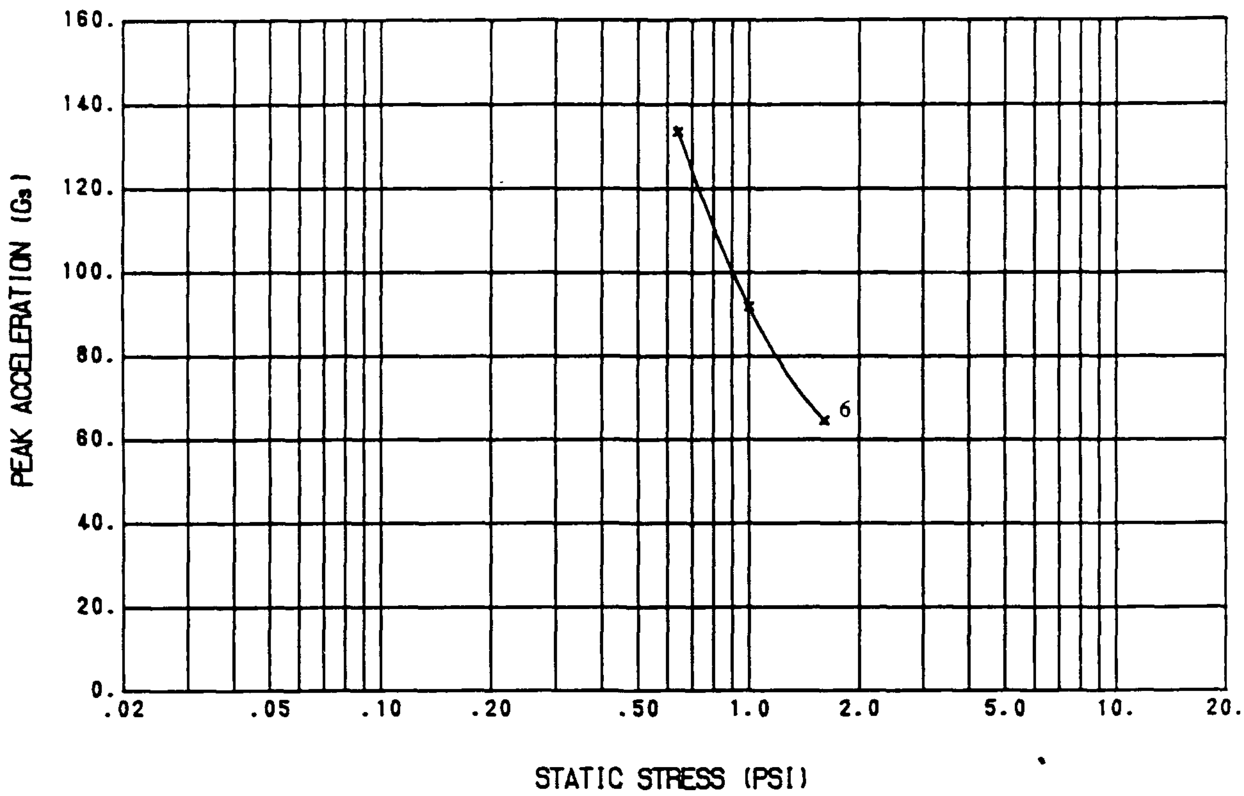

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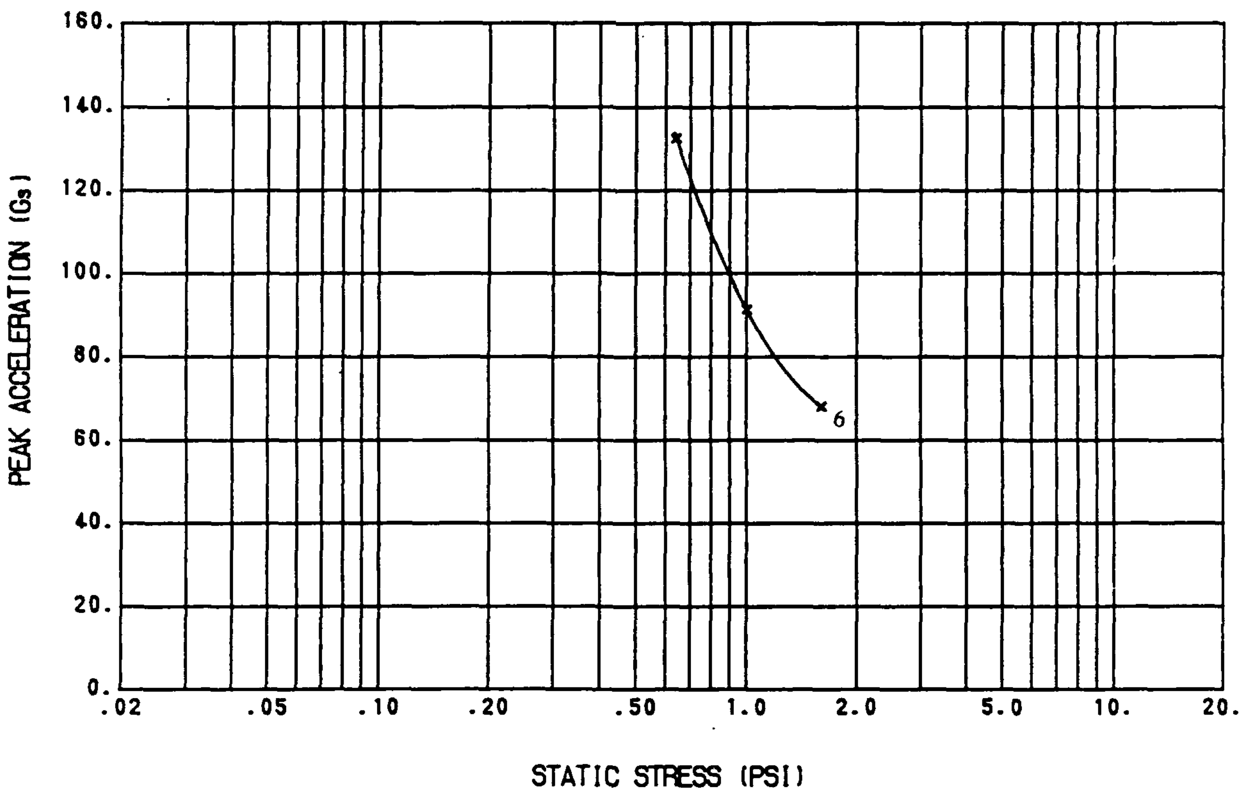

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APPENDIX 3

REPORT DOCUMENTATION

REPORT DOCUMENTATION PAGE

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1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
Jul 93

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
Evaluation of Cushioning Materials for Munitions Packaging

5. FUNDING NUMBERS

6. AUTHOR(S)
David E. Filsinger

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Packaging Evaluation Activity
5215 Thurlow St.
Wright-Patterson AFB, OH 45433-5540

8. PERFORMING ORGANIZATION REPORT NUMBER
93-R-01

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U.S. Army Armament Research,
Development, and Engineering Center
Picatinny Arsenal, NJ 07806-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
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11. SUPPLEMENTARY NOTES
N/A

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unlimted

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

At the request of the Army Material Command (SMCAR) the Air Force Packaging Evaluation Activity has performed extensive dynamic cushioning tests on four grades of polyethylene cushioning material. The purpose of this testing was to generate new cushioning design curves that would define the cushioning properties of polyethylene over a greater range of drop heights and material thicknesses than those curves presently available.

It should be noted that all testing was performed on old materials blown with a chlorofluorocarbon (CFC) blowing agent. Therefore, the curves generated may not be representative of current materials produced using CFC free blowing agents.

14. SUBJECT TERMS
Foam, Cushioning, Dynamic Cushioning, Polyethylene

15. NUMBER OF PAGES
38

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	